Full Band Capture Revisited

A Technical Paper prepared for SCTE•ISBE by

Ron Hranac
Technical Marketing Engineer
Cisco Systems
9155 E. Nichols Ave., Ste. 400, Centennial, CO 80112
+1-720-875-1338
rhranacj@cisco.com

and

Chad Campbell, Intraway

Roger Fish, Broadcom

Tom Kolze, Broadcom

Even Kristoffersen, Telia Norge

James Medlock, Akleza

Jason Rupe, CableLabs

Paul Schauer, Comcast

Aleksander Soeberg, Telia Norge

Tom Williams, CableLabs

Larry Wolcott, Comcast

ENTROPIC EXHIBIT 2020
Comcast v. Entropic
IPR2024-00441

Table of Contents

Title **Page Number**

1. Introduction 5
2. FBC Benefits 7
3. A Closer Look at Impairment Categories 9
4. How FBC Works 10
   4.1. General Operation 10
   4.2. FBC Controls 11
5. FBC Examples 12
   5.1. FBC Use Cases 17
      5.1.1. Water damaged drop 18
      5.1.2. Localizing a problem to a specific drop 20
      5.1.3. FBC Analysis and Fault Location Example 22
6. How to retrieve and Display FBC Data 27
   6.1. FBC Data Collection 27
7. Advanced FBC Applications 35
   7.1. Estimating Distances with High Accuracy 35
   7.2. Drop Cable Testing 37
   7.3. Using FBC to View Upstream Noise 37
   7.4. Using FBC to Find Water-Soaked Coaxial Cable 38
8. Impairment Detection 39
   8.1. Impairment detection and automation 40
9. Conclusion 41
10. Abbreviations 41
11. Bibliography & References 42
12. Appendix 44
   12.1. File: getFbcData.py 44
   12.2. File: showFbcData.py 45

List of Figures

Title **Page Number**

Figure 1. Spectrum analyzer screen shot showing analog TV signals on the left side and digital signals on the right side. The vertical axis is amplitude, and the horizontal axis is frequency. 5
Figure 2. FBC screen shot of a cable network's downstream spectrum from a DOCSIS modem in the home of one of the authors (courtesy of Comcast) 6
Figure 3. FBC screen shot of a cable network's downstream spectrum. This display shows a suckout (notch) at about 625 MHz (courtesy of Broadcom). 6
Figure *4*. FBC from modem in lab setup (see text). Courtesy of CableLabs. 7
Figure *5*. Spectrum analyzer display of the same RF spectrum in Figure 4 (courtesy of CableLabs). 8
Figure *6*. Examples of some impairments found using FBC (courtesy of Comcast). 9
Figure 7. Digital spectrum analyzer block diagram (see text). 11
Figure *8*. Adjacency – While the spectrum is relatively flat, note that signals below 400 MHz are a few dB higher in amplitude than signals above 400 MHz. This suggests incorrect RF level adjustment in the headend or hub site (courtesy of Comcast). 12
Figure *9*. Filter – Indicates the presence of a filter in the subscriber drop (courtesy of Comcast). 13

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Figure *10*. Negative tilt – Typical response at or near ends-of-line locations, but excessive negative tilt could indicate a problem. Note presence of what appears to be FM broadcast band ingress at the left end of the display (courtesy of Akleza)..... 13
Figure *11*. Positive tilt – Typical response at or near the output of nodes and amplifiers. Note presence of what appears to be FM broadcast band ingress at the left end of the display (courtesy of Akleza)..... 14
Figure *12*. Standing wave – Classic example of scalloped sinusoidal wave shape in the response, caused by an impedance mismatch (courtesy of Akleza)..... 14
Figure *13*. Suckout – Notch in the response, centered just above 700 MHz (courtesy of Akleza)..... 15
Figure *14*. Suckout - A severe example, centered between 500 MHz and 600 MHz (courtesy of Comcast)..... 15
Figure *15*. Water damage - Non-periodic wave shape in the response and higher attenuation at higher frequencies, typical of water damage in a subscriber drop (courtesy of Akleza)..... 16
Figure *16*. Resonant peaking – Day 1 FBC spectrum (courtesy of Comcast)..... 16
Figure *17*. Resonant peaking - Day 2 FBC spectrum, same modem as previous figure (courtesy of Comcast)..... 17
Figure *18*. Resonant peaking – Day 3 FBC spectrum, same modem as previous two figures. Note that the problem seems to have disappeared (courtesy of Comcast)..... 17
Figure *19*. Resonant peaking - Day 4 FBC spectrum, same modem as previous three figures. The response problem has returned (courtesy of Comcast)..... 17
Figure *20*. Water damage before repair. Note the non-periodic wave shape in the FBC response and the higher attenuation at higher frequencies. This particular example occurred when abrasion damaged the cable's jacket, allowing water to enter the cable (see text). Courtesy of Comcast..... 18
Figure *21*. Most of the downstream SC-QAM signals have low signal level and degraded RxMER, indicated in red shaded boxes. The upstream was relatively unaffected (courtesy of Comcast)..... 18
Figure *22*. Damaged coax jacket where water was able to enter the cable..... 19
Figure *23*. Water coming out of the end of the connector at the ground block..... 19
Figure *24*. FBC response after drop cable was replaced from the tap to the ground block (courtesy of Comcast)..... 20
Figure *25*. Signal performance after the drop was replaced (courtesy of Comcast)..... 20
Figure *26*. Subscriber A's FBC showing 4G/LTE and 5G ingress (courtesy of Telia Norge)..... 21
Figure *27*. Subscriber B's FBC, showing no 4G/LTE or 5G ingress (courtesy of Telia Norge)..... 21
Figure *28*. Location of cell site near the affected subscriber drop..... 22
Figure 29. Example of using FBC to isolate a standing wave fault (courtesy of Akleza)..... 23
Figure 30. Amplifier [1] containing water and showing corrosion (courtesy of Akleza)..... 24
Figure 31. Fault still visible after replacement of amplifier [1] (courtesy of Akleza)..... 25
Figure 32. Amplifier [2] with corroded connector (courtesy of Akleza)..... 26
Figure 33. FBC trace after faulty connector replaced (courtesy of Akleza)..... 26
Figure *34*. IF3-MIB spectrum capture objects..... 28
Figure *35*. Configuration example for high resolution downstream data collection..... 29
Figure *36*. Returned SNMP table row for each frequency span..... 29
Figure *37*. FBC plot using Microsoft Excel (courtesy of Akleza)..... 31
Figure *38*. FBC plot generated using example Python scripts (courtesy of Akleza)..... 31
Figure *39*. FBC plot with no averaging (courtesy of Akleza)..... 32
Figure *40*. FBC plot with 32 averages (courtesy of Akleza)..... 33
Figure *41*. Zoomed view of high resolution and averaged FBC (courtesy of Akleza)..... 34

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Figure *42*. Diagrams showing what is observed at two points on a cable line for the one- and two-reflection cases. The inpulse responses on the right can be observed by the FBC and the inpulse responses can be observed by an active or passive TDR. 36
Figure *43*. Damaged hardline coax that was at one end of an echo tunnel; the other end was a loose seizure screw on a chassis terminator installed in an end-of-line tap. Further complicating things: The damaged cable was submersed in water. Courtesy of CableLabs. 36
Figure *44*. Water-soaked coax, FBC plot on left and impulse response on right. The impulse response is highly dispersed. 39
Figure *45*. Coax with standing wave response. FBC plot is on left and impulse response is on right. The impulse response is not dispersed. 39

© 2020 SCTE•ISBE and NCTA. All rights reserved.

1. Introduction

One of the most versatile pieces of test equipment available to the cable industry is the spectrum analyzer. Spectrum analyzers, which are instruments that display signals in the frequency domain (see ***Figure 1***) have for decades been used for headend, hub site, and outside plant maintenance and troubleshooting. However, spectrum analyzers have historically been expensive and not typically available to field personnel; usually not particularly portable; and in some cases, complicated to use.

That said, wouldn't it be nice to have a spectrum analyzer in every cable subscriber's home? What if those in-home spectrum analyzers could be remotely accessed so that technicians didn't have to go to each home to use them? Even better, what if that in-home spectrum analyzer capability already existed and was widely deployed?

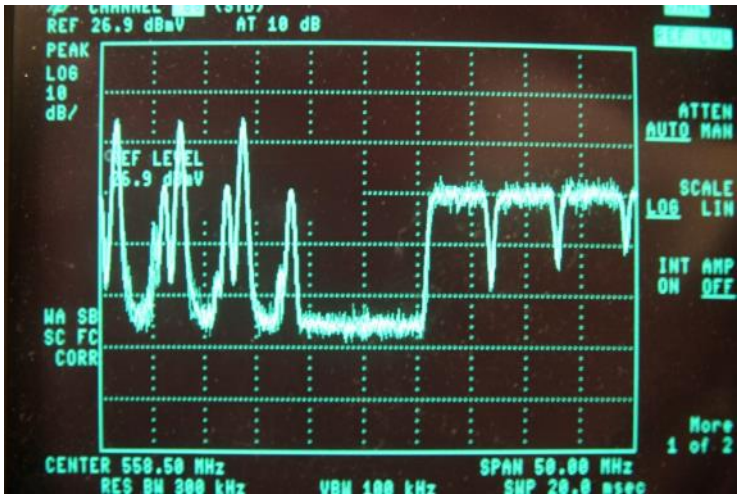

Figure 1. Spectrum analyzer screen shot showing analog TV signals on the left side and digital signals on the right side. The vertical axis is amplitude, and the horizontal axis is frequency.

Let's answer those three questions in reverse order, starting with the last one first: In-home spectrum analyzer capability does exist and has for several years. Those in-home spectrum analyzers can be remotely accessed, using simple network management protocol (SNMP) or similar. And while not in every cable subscriber's home, they are in a sizeable percentage of homes with Data-Over-Cable Service Interface Specifications (DOCSIS®) customer premises equipment (CPE).

That in-home spectrum analyzer capability is known as full band capture (FBC) and is a cable modem spectrum analysis feature available in DOCSIS 3.0 and 3.1 cable modems. Cable modem spectrum analysis functionality was first defined in version I20 of the DOCSIS 3.0 Operations Support System Interface Specification (CM-SP-OSSIv3.0-I20-121113) back in November 2012.[1] See [Ref. 1].[2]

Figure 2 shows an example of an FBC display of the downstream in a cable network. The data was captured remotely from an FBC-capable DOCSIS modem in the home of one of the authors, showing a problem-free downstream spectrum. The vertical axis is amplitude (dBmV), the horizontal axis is frequency in MHz, and the resolution bandwidth (RBW) is 117 kHz.

[1] The DOCSIS 3.0 specifications were first published in 2006, and the first DOCSIS 3.0 cable modems were certified by CableLabs in 2008.
[2] References are in the bibliography near the end of the document.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

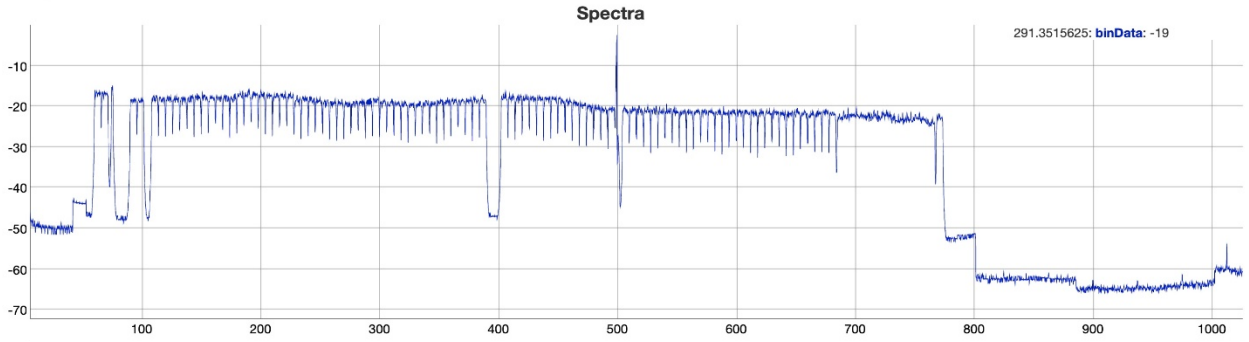

Figure 2. FBC screen shot of a cable network's downstream spectrum from a DOCSIS modem in the home of one of the authors (courtesy of Comcast).

Figure 3 shows another example of an FBC display of the downstream spectrum in a cable network. The display was captured remotely from an FBC-capable DOCSIS modem in a cable subscriber's home, and shows a suckout (notch) in the vicinity of 625 MHz that would otherwise have been difficult to identify without having a technician on-site. As before, the vertical axis is amplitude (dBmV), the horizontal axis is frequency in MHz, and the RBW is 117 kHz.

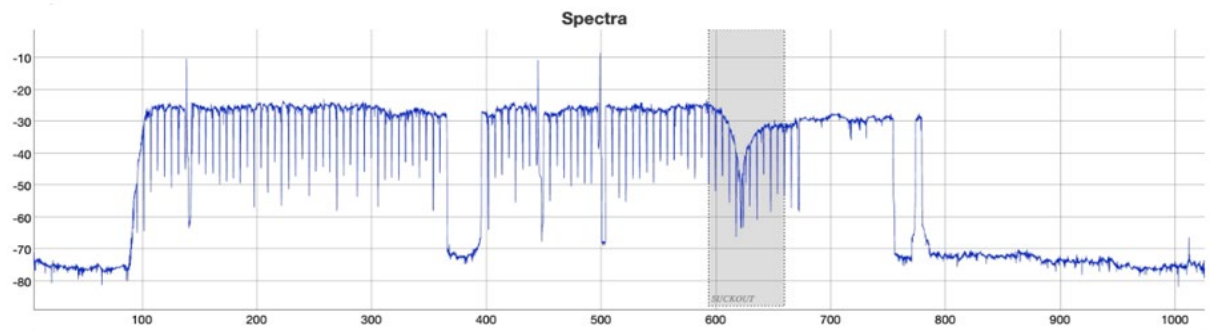

Figure 3. FBC screen shot of a cable network's downstream spectrum. This display shows a suckout (notch) at about 625 MHz (courtesy of Broadcom).

Some operators have been using FBC successfully as part of their proactive network maintenance (PNM) programs. But many operators have not taken advantage of FBC, perhaps because they don't know about it, or don't know how to use it. Whatever the reason, FBC is a powerful tool that is supported in most DOCSIS 3.0 and all DOCSIS 3.1 cable modems.

This paper highlights the benefits of FBC; provides an overview of how FBC works; shows several examples of the types of impairments that can be identified using FBC, along with some use cases demonstrating how cable operators use FBC to troubleshoot specific problems; and explains how to retrieve and display spectral data from modems (example Python code to retrieve and plot FBC data can be found in the Appendix). Also included is a discussion about using FBC for displaying upstream spectral data – especially noise – a capability supported in some cable modem implementations. Finally, the paper provides guidance and findings about how to transform the visual spectrum data into actionable decisions, including opportunities for automation, and operational expenditure savings.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

2. FBC Benefits

As mentioned previously, FBC is being used by several cable operators as part of PNM programs, both in standalone tools and in third party PNM tools. FBC enables operators to have spectrum analysis capabilities wherever FBC-capable DOCSIS 3.0 and 3.1 cable modems have been deployed.
Is FBC really like having a spectrum analyzer in subscribers' homes? **Figure** 4 and **Figure** 5 show a lab setup comparing the screen shot from an FBC-equipped cable modem with a screen shot from a Keysight spectrum analyzer. Single carrier quadrature amplitude modulation (SC-QAM) signals are located at the low end of the spectrum starting at 261 MHz. Two orthogonal frequency division multiplexing (OFDM) signals are located between about 408 MHz to 600 MHz and 608 MHz to 800 MHz respectively. A continuous wave (CW) carrier is present at 303 MHz. A filter created a deep notch at about 337 MHz, and a 5 MHz to 750 MHz bandpass filter rolled off the higher OFDM signal about 25 dB from 750 MHz to 800 MHz.

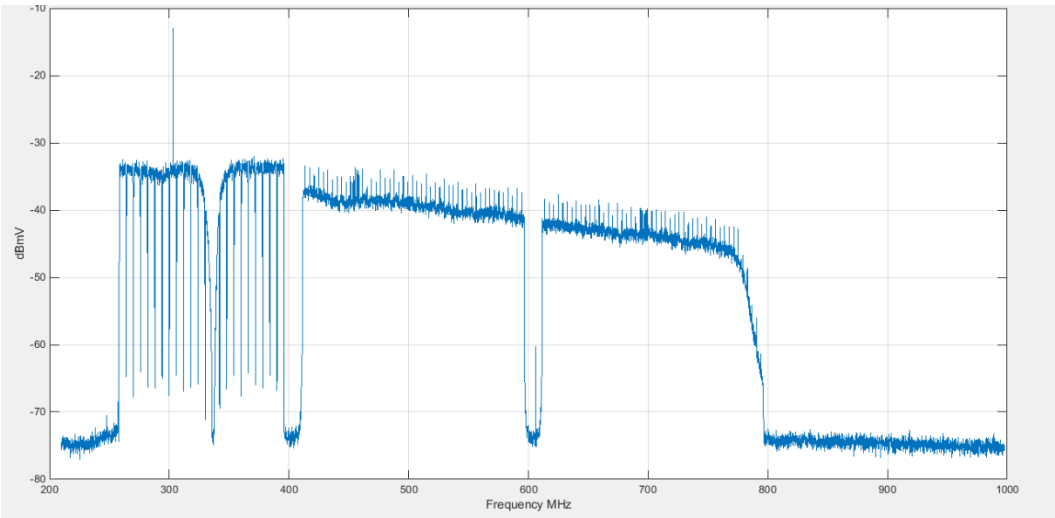

Figure 4. FBC from modem in lab setup (see text). Courtesy of CableLabs.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

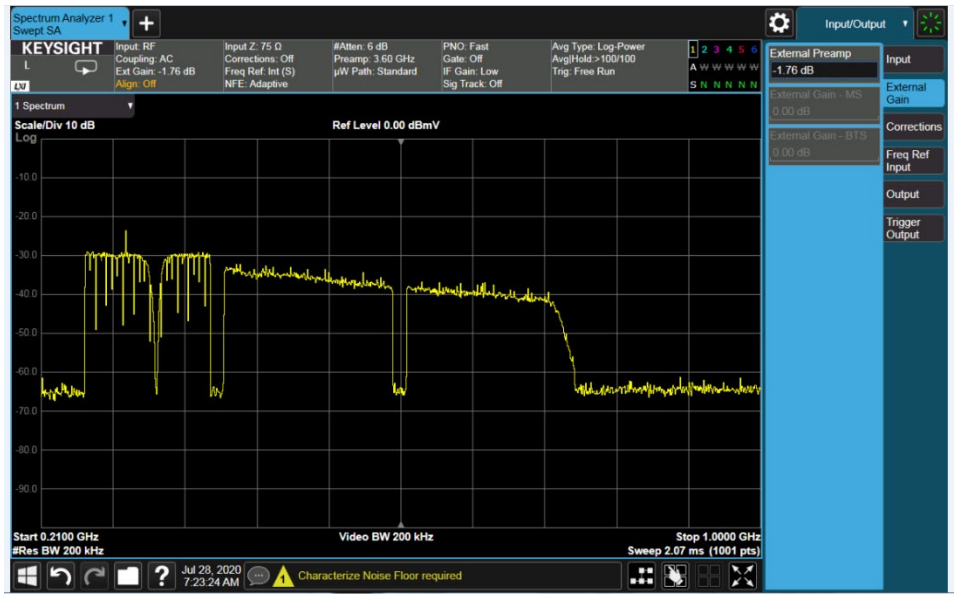

Figure 5. Spectrum analyzer display of the same RF spectrum in Figure 4 (courtesy of CableLabs).

FBC allows operators to obtain remote spectrum captures at the subscriber premises without having to take an expensive spectrum analyzer into the field; without requiring access into subscribers' homes; and without having to roll a truck to identify problems! Key benefits of FBC include significant operational advantages, not to mention operational cost savings.

With a substantial number of FBC-capable DOCSIS cable modems already deployed, these devices have gathered critical mass and are now in a large percentage of subscribers' homes. As such, operators can use FBC to identify individual drop problems, and correlate RF spectrum signatures from neighboring modems to troubleshoot and locate distribution network problems affecting groups of modems.

The width of the FBC spectrum – the full downstream spectrum (and sometimes also the upstream spectrum, depending on modem implementation) – allows operators to detect very short micro-reflections not visible when just a single channel is analyzed through adaptive equalization or pre-equalization. FBC has enabled verification of channel RF level alignment – for instance, incorrect narrowcast injection signal levels – and the detection of ingress. Correlation of FBC signatures before and after actives enables the detection of nonlinear problems in amplifiers. And much, much more. **Figure** 6 shows examples of some of the impairments that can be identified using FBC. Additional examples are included later in this paper.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

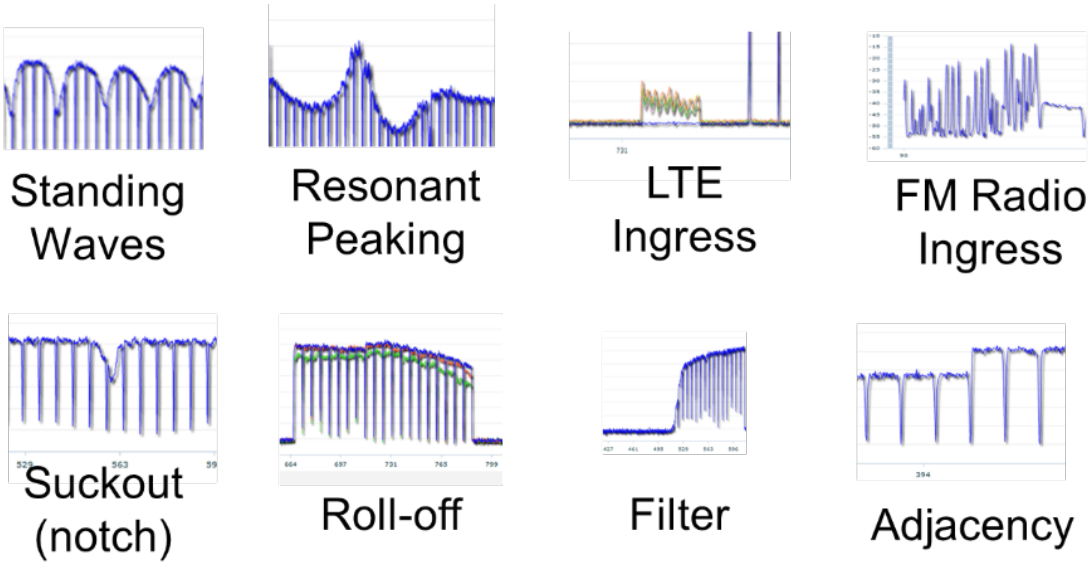

Figure 6. Examples of some impairments found using FBC (courtesy of Comcast).

Clearly, having the equivalent of a spectrum analyzer in every home that has an FBC-capable modem provides powerful troubleshooting and maintenance capabilities. That said, it is simply not practical for cable operators to manually look at every modem's FBC spectrum data. What to do? Automated spectrum signature analysis and impairment detection are available to scale the analysis to the millions of modems deployed with FBC functionality, and are discussed later in Section 8. All of this can be done remotely!

3. A Closer Look at Impairment Categories

Impairments to an FBC's spectrum can be broken into two classes or categories: things that are added to the FBC that should not be there, and downstream signals that have been modified from their original unimpaired state. Fortunately, most downstream SC-QAM and OFDM signals appear to have a relatively static noise-like appearance to a spectrum analyzer, but this is not true for upstream signals.

Energy that is added includes:

- Random noise from plant nonlinear distortion or from too-low RF levels.
- Wideband ingressors such as LTE signals and UHF TV broadcast signals, entering the network via shielding problems in the hardline distribution network or subscriber drop (including inside the home).
- Narrowband signals like broadcast FM radio and amateur radio transmissions, entering the network via shielding problems in the hardline distribution network or subscriber drop (including inside the home).
- House wiring noise. House wiring noise can enter the cable plant through defective coaxial cable shielding, which is unfortunately pervasive. [Ref. 2] estimates that 12% to 20% of houses have defective cable shielding and can pass noise from house electrical wiring to the cable plant. House wiring noise is harder to detect and measure because it is often intermittent, usually impulsive in nature, and concentrated in the upstream band, which is visible only with cable modem FBC hardware that has an upstream view capability. Such modems are already deployed in the field (more on this later),
- FBC measurement artifacts, such as an elevated noise floor and spurious signals. These generally are relatively small and easy to identify.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Things that modify the waveform include:

- Adjacency – One example is incorrect narrowcast RF signal levels compared to the rest of the downstream spectrum.
- Filter – Indicates the presence of a filter (e.g., a high-speed data-only filter).
- Non-periodic waves – A response impairment that occurs in the presence of distributed impedance mismatches that can be caused by, for example, water in the coaxial cable.
- Resonant peaking – Usually caused by a loose module, circuit board, poor grounding, etc., in an active or passive device.
- Rolloff – Low-end rolloff is usually caused by a loose center conductor seizure screw or similar. Higher-frequency rolloff is caused by water, or damaged cable or equipment.
- Standing waves – Periodic scalloped sinusoidal or sinusoidal-like amplitude ripple in the frequency response is created by discrete impedance mismatches.
- Suckout – Notch in the frequency response affecting one or more channels, caused by loose modules, module covers, printed circuit boards, poor grounding, and similar problems inside of active or passive device housings. Can also be caused by repetitive, regularly spaced impedance discontinuities in coaxial cable.
- Tilt – Some upward or downward tilt is normal, but excessive downward tilt is indicative of a problem.

Because a cable operator may have many millions of cable modems in its plant, and because the artifacts can be dynamic, as mentioned previously software exists that can automatically detect and report on both added and modified impairments. The power of human eyes and brains is assisted greatly by sophisticated PNM software algorithms processing thousands of FBC responses in batch mode.

Several examples of FBC spectrum displays showing a variety of impairments are included in Section 5.

4. How FBC Works

4.1. General Operation

FBC is a feature that uses low-cost discrete Fourier transform (DFT) and fast Fourier transform (FFT)-based technology to support spectrum analyzer-like functionality in many DOCSIS 3.0 and all DOCSIS 3.1 cable modems.

As mentioned earlier, FBC spectrum data can be accessed remotely using SNMP or similar, allowing a cable operator to see where various impairments might be problematic from the perspective of the modems and without the need to be on-site at the subscriber premises.

Spectrum analyzers are instruments used to measure the frequency content of an input signal. This is also what DFT does. Multiplying the input signal by what is called a DFT matrix measures the correlation of that input signal with each row in the DFT matrix, and each row is a sine/cosine of a particular frequency. Thus, each output bin represents the power of the input signal at that frequency with a complex value which corresponds to the amplitude and phase of that frequency component within the input signal.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

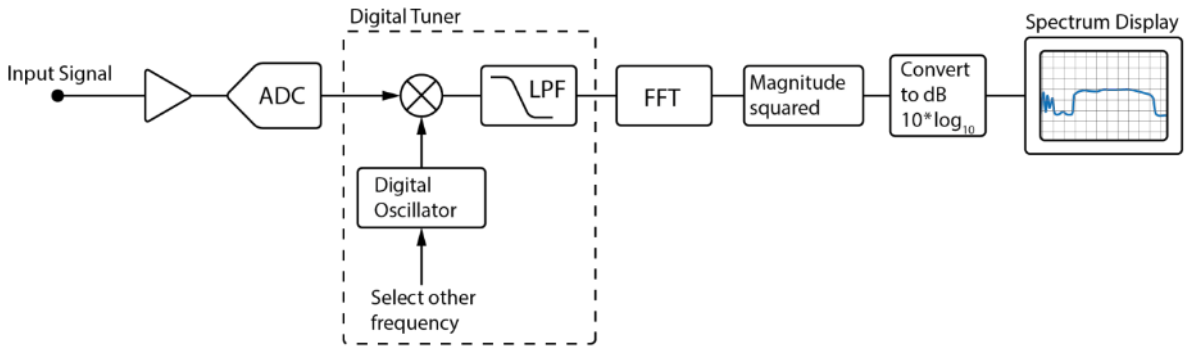

Figure 7. Digital spectrum analyzer block diagram (see text).

Figure 7 shows a block diagram of a digital spectrum analyzer which could reside in a cable modem. The input signal enters at the left of the diagram; this signal is the full upstream or downstream band of the cable plant. An analog front end (represented by a small triangle in the figure) amplifies the signal and provides RF gain control. A high-speed analog-to-digital converter (ADC) provides digital samples of the signal. A digital tuner, consisting of a digital oscillator and lowpass filter, selects the desired analysis band around a specified center frequency. The signal from the selected band is applied to the FFT, which multiplies the signal by the DFT matrix. Each bin of the FFT output comprises a complex value consisting of two numbers, real (I) and imaginary (Q), giving the correlation of the input signal with the particular frequency corresponding to a single row of the DFT matrix. Typically, a spectrum analyzer is only concerned with the magnitude, not the phase, of the FFT output. So, the power (magnitude-squared) of each bin is computed, that is, $I^2 + Q^2$ for each bin. If spectrum smoothing is to be applied, the previously-described process is repeated with a fresh set of data from the same band, and the power values from several captures are averaged at each bin location. The smoothed bins are converted to decibels by taking $10*\log_{10}$ of each bin power value. The decibel values, one for each frequency bin, are displayed as the spectrum of the input signal.

If the entire band is able to be processed as a single analysis band, the tuner shown in ***Figure 7*** is not necessary. However, if the band is being analyzed in segments, then the tuner is used to step through a sequence of analysis segments of the full band, and the individual spectrum segments are spliced together to produce the overall wideband spectrum.

4.2. FBC Controls

The cable modem FBC feature is defined by the CmSpectrumAnalysis management information base (MIB) object in the CableLabs DOCSIS 3.1 CM OSSI specification [Ref. 3]. The CmSpectrumAnalysisCtrlCmd MIB provides a set of attributes which are used to configure and enable a spectrum capture. The cable modem spectrum capture is performed over a set of spectral segments where the segment width is defined by the SegmentFrequencySpan and the entire capture is defined by the FirstSegmentCenterFrequency, LastSegmentCenterFrequency and NumBinsPerSegment. WindowFunction allows selection from an assortment of windows. The RBW is a function of the NumBinsPerSegment but is scaled by an amount related to the WindowFunction in use for the capture; the reported RBW (units of Hz) is used to multiply an input signal or noise flat power spectral density (PSD, or dBmV per Hz) to yield the power (dBmV) measured in each bin: Flat PSD (dBmV/Hz) times RBW (Hz) equals bin power (dBmV). The frequency-resolving capability of the window, which is similar to the frequency span of its passband, is different than the RBW, and is described by the EquivalentNoiseBandwidth MIB object. This object is a unitless number relating the ratio of the window

© 2020 SCTE•ISBE and NCTA. All rights reserved.

frequency span divided by the FFT bin spacing. At least one vendor has scaled the application of the window function such that the RBW is always equal to the bin spacing, but the frequency-resolving capability is still described by the EquivalentNoiseBandwidth MIB object. An averaging feature, NumberOfAverages, is available for the FBC which uses the leaky integrator method. The averaging feature is very useful in that the averaging is performed by the cable modem software prior to making the data available. The data for a particular capture can be retrieved using the CmSpectrumAnalysisMeas object or by using the Bulk Data CM Spectrum Analysis File uploaded via TFTP. Additional details are discussed in Section 6.

The CableLabs specification has no requirements with respect to the accuracy of the spectrum analysis feature. However, the measurement inherits accuracy from the cable modem requirement to report the power per 6 MHz in any downstream channel with an accuracy of ±3 dB. The amplitude data which is made available as just described uses 16 bit two's complement notation in units of hundredths dBmV per bin.

5. FBC Examples

This section includes several examples of FBC screen shots from operating cable networks. The examples highlight some of the more common impairments that can be identified using FBC. In systems where FBC is being used, technicians' comment that the spectrum analyzer-like displays are very intuitive and easy to interpret. Use case examples with more detailed information about the problems observed are included, too.

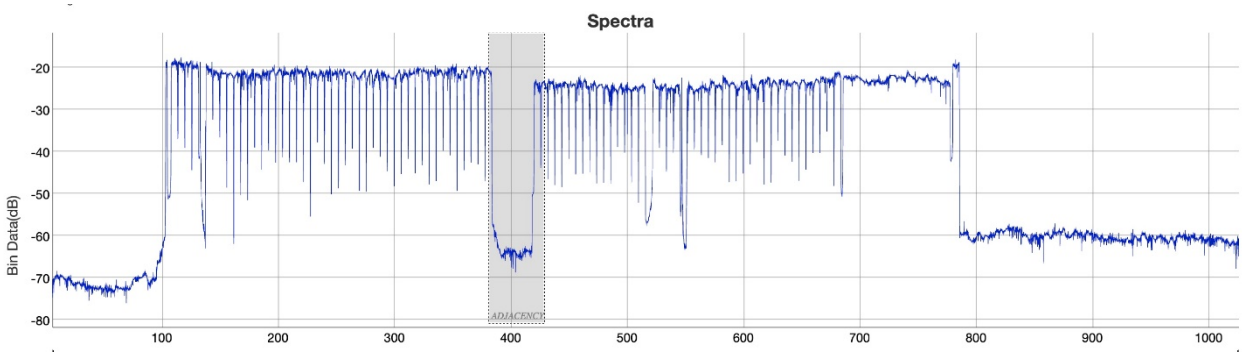

Figure 8. Adjacency – While the spectrum is relatively flat, note that signals below 400 MHz are a few dB higher in amplitude than signals above 400 MHz. This suggests incorrect RF level adjustment in the headend or hub site (courtesy of Comcast).

© 2020 SCTE•ISBE and NCTA. All rights reserved.

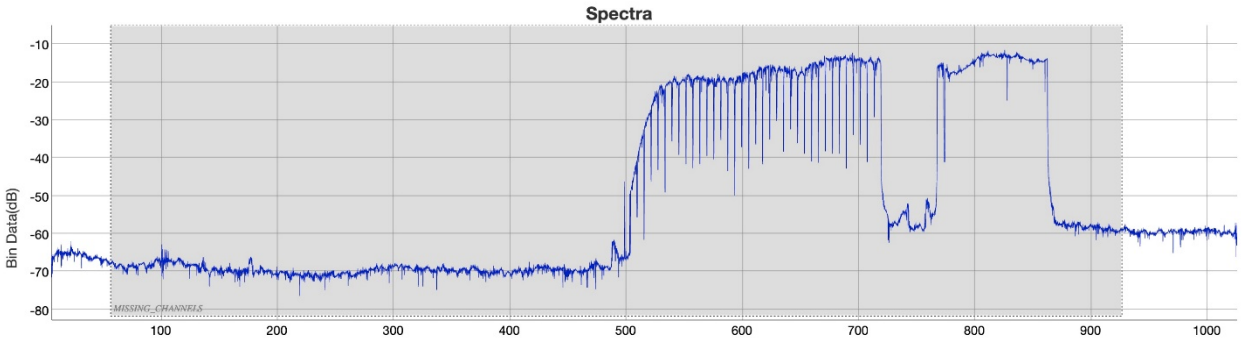

Figure 9. Filter – Indicates the presence of a filter in the subscriber drop (courtesy of Comcast).

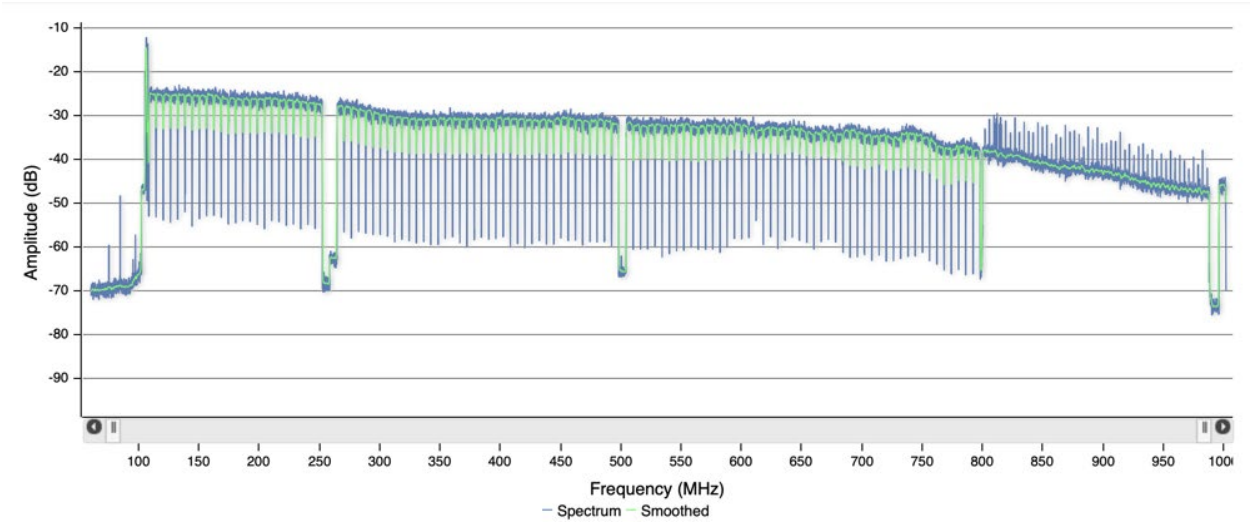

Figure 10. Negative tilt – Typical response at or near ends-of-line locations, but excessive negative tilt could indicate a problem. Note presence of what appears to be FM broadcast band ingress at the left end of the display (courtesy of Akleza).

© 2020 SCTE•ISBE and NCTA. All rights reserved.

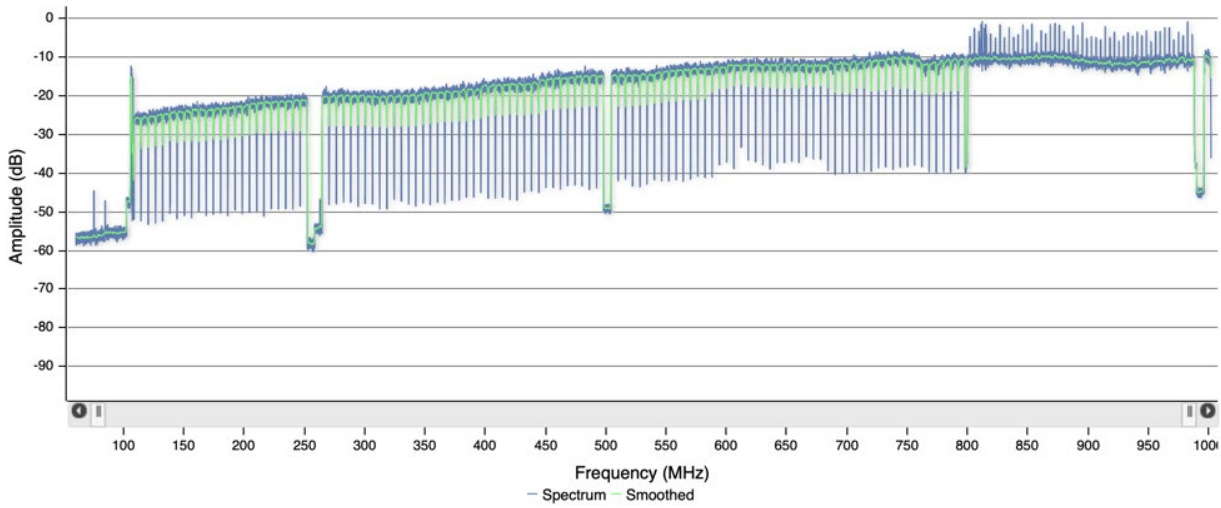

Figure 11. Positive tilt – Typical response at or near the output of nodes and amplifiers. Note presence of what appears to be FM broadcast band ingress at the left end of the display (courtesy of Akleza).

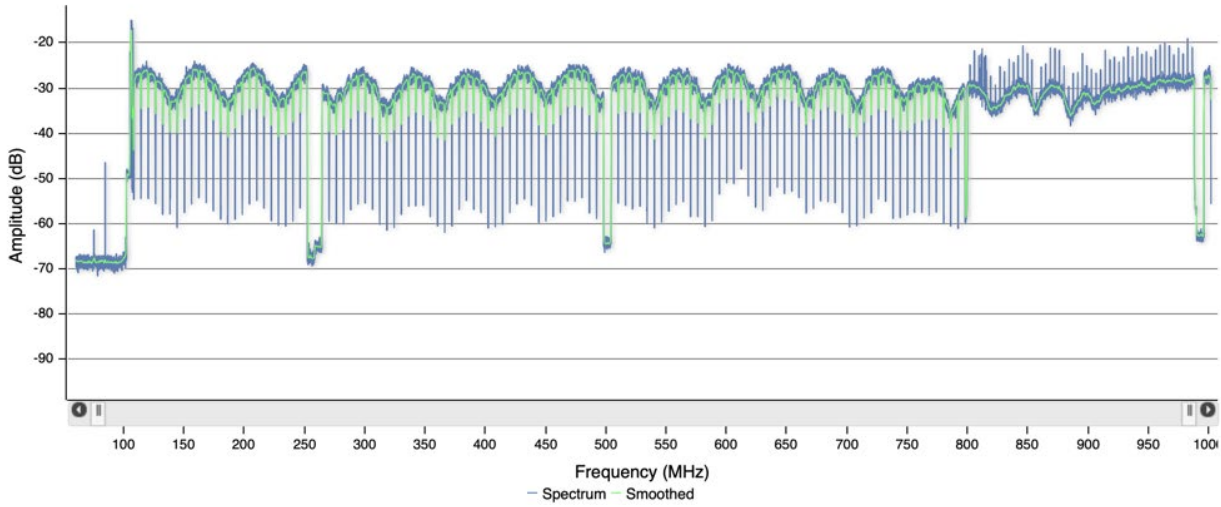

Figure 12. Standing wave – Classic example of scalloped sinusoidal wave shape in the response, caused by an impedance mismatch (courtesy of Akleza).

© 2020 SCTE•ISBE and NCTA. All rights reserved.

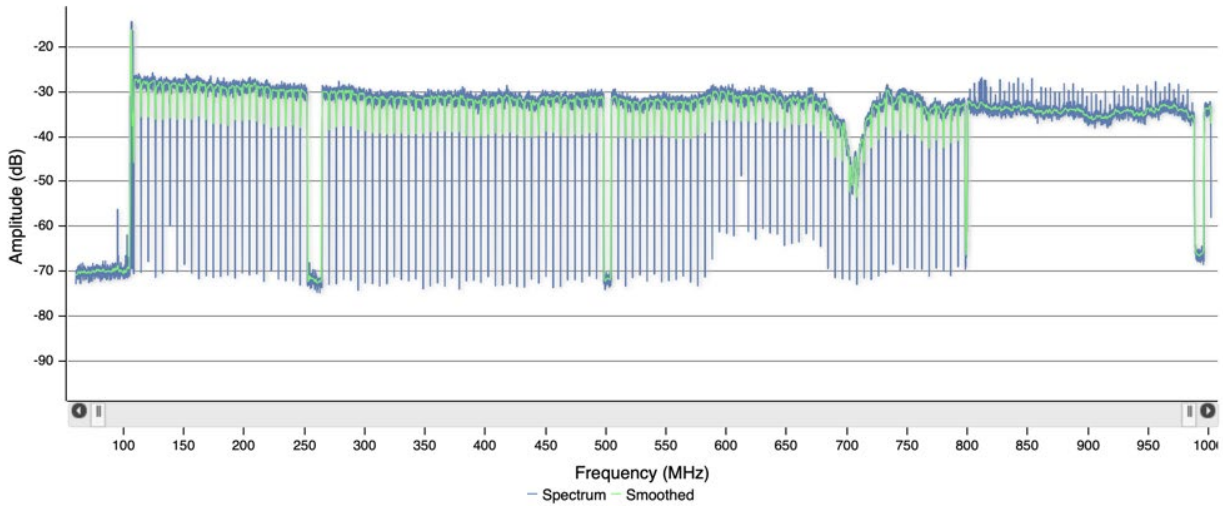

Figure 13. Suckout – Notch in the response, centered just above 700 MHz (courtesy of Akleza).

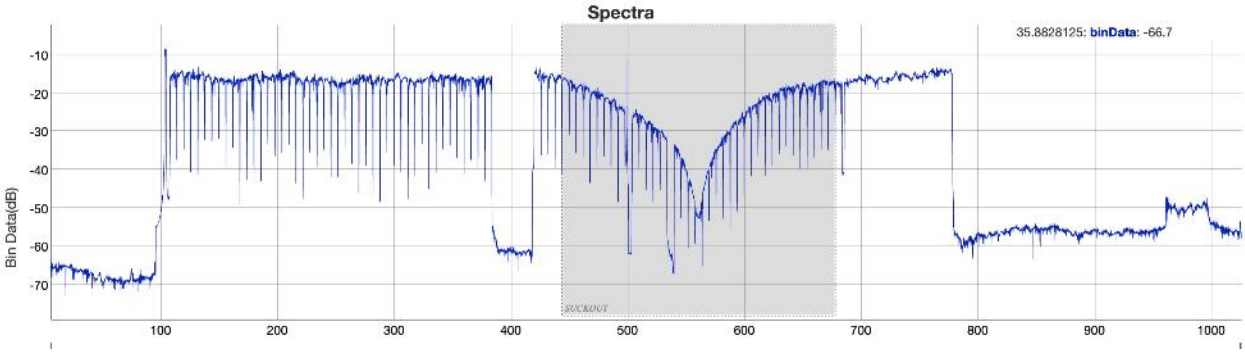

Figure 14. Suckout - A severe example, centered between 500 MHz and 600 MHz (courtesy of Comcast).

© 2020 SCTE•ISBE and NCTA. All rights reserved.

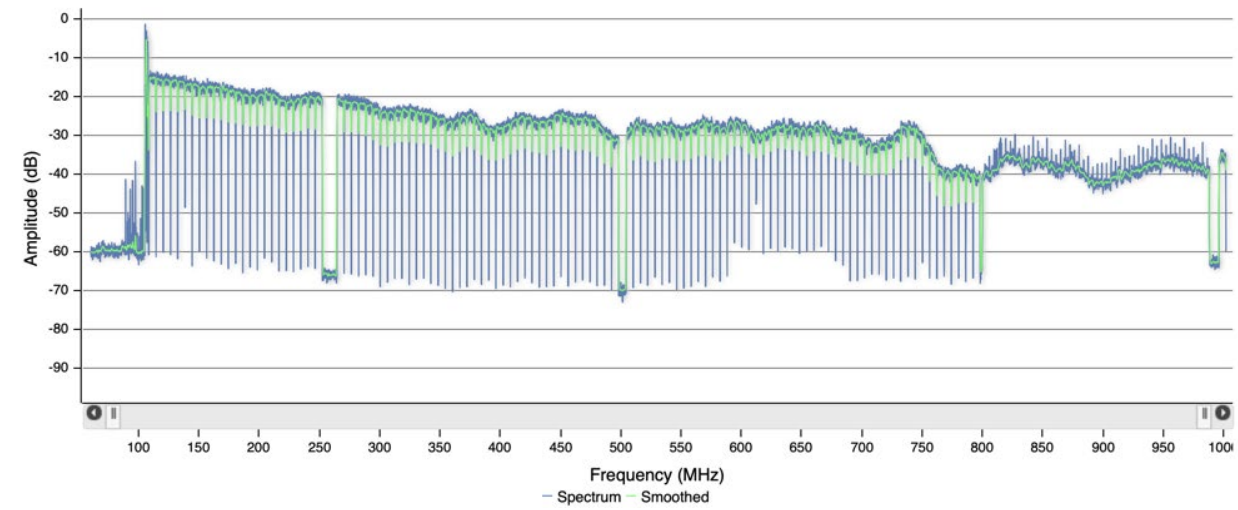

Figure 15. Water damage - Non-periodic wave shape in the response and higher attenuation at higher frequencies, typical of water damage in a subscriber drop (courtesy of Akleza).

The next four figures show resonant peaking varying over a four-day period. An important note: Should a varying response problem such as resonant peaking occur in the vicinity of the cable network's AGC pilot, amplifier operation will be affected and signal levels will vary, too. Tracking down what is often an intermittent problem like this is usually difficult, but FBC can be a valuable tool to help quickly identify and locate the source.

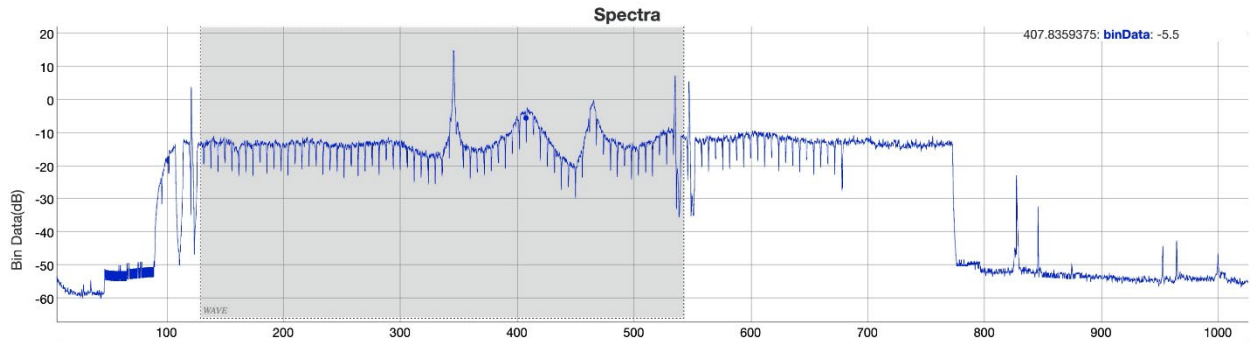

Figure 16. Resonant peaking – Day 1 FBC spectrum (courtesy of Comcast).

© 2020 SCTE•ISBE and NCTA. All rights reserved.

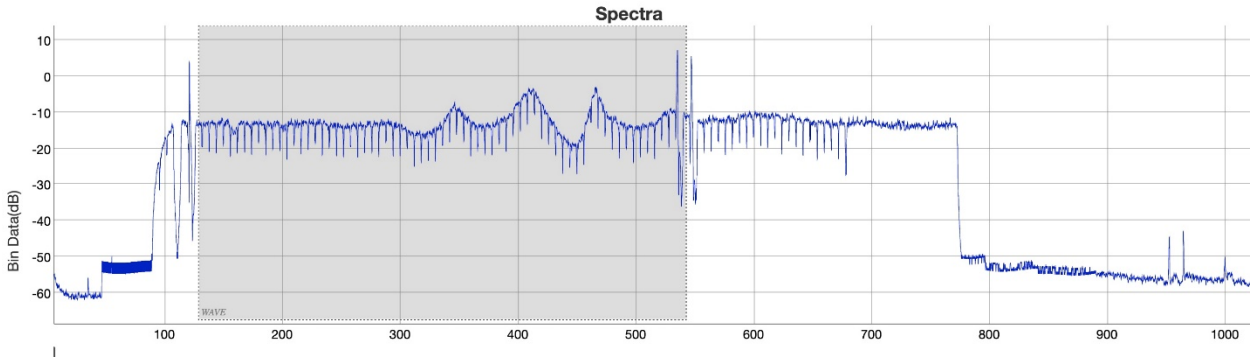

Figure 17. Resonant peaking - Day 2 FBC spectrum, same modem as previous figure (courtesy of Comcast).

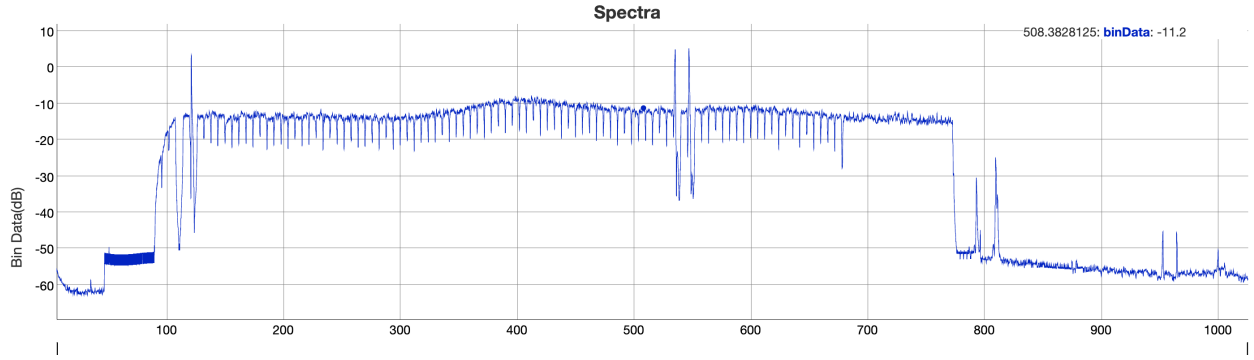

Figure 18. Resonant peaking – Day 3 FBC spectrum, same modem as previous two figures. Note that the problem seems to have disappeared (courtesy of Comcast).

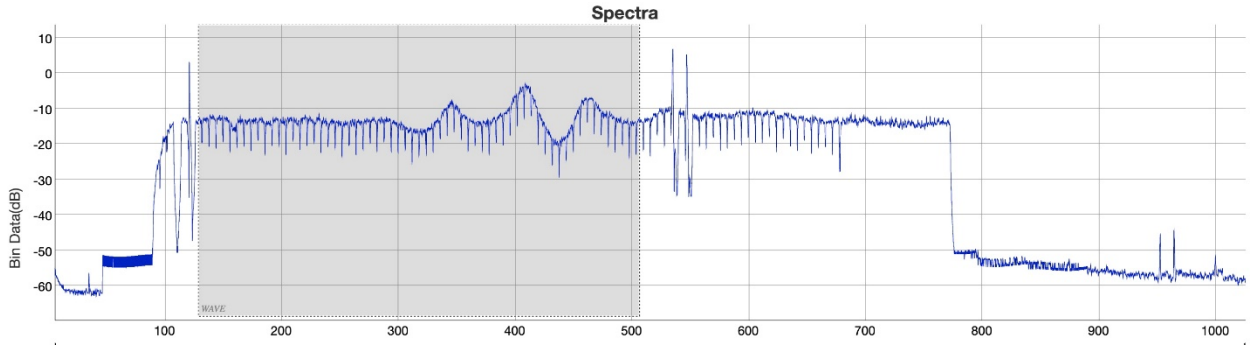

Figure 19. Resonant peaking - Day 4 FBC spectrum, same modem as previous three figures. The response problem has returned (courtesy of Comcast).

5.1. FBC Use Cases

The following examples include additional details related to the use of FBC to troubleshoot problems.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

5.1.1. Water damaged drop

FBC was used to identify an individual subscriber drop that had water damage, specifically by the unique signature in the displayed frequency response. As ***Figure 20*** shows, the response has a non-periodic wave shape, and attenuation increases dramatically at higher frequencies. Remote polling of the modem showed that most of the downstream SC-QAM signals had poor performance, as shown in ***Figure 21***. The upstream was relatively unaffected.

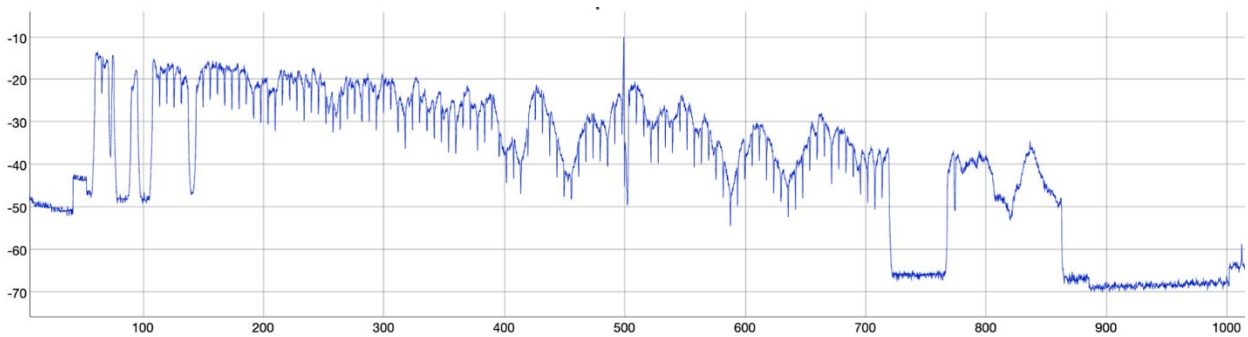

Figure 20. Water damage before repair. Note the non-periodic wave shape in the FBC response and the higher attenuation at higher frequencies. This particular example occurred when abrasion damaged the cable's jacket, allowing water to enter the cable (see text). Courtesy of Comcast.

Device Health																									
Registration State	6 (Online)																								
Down Rx Power	-18.5	-24.7	-28.3	-19.5	-19.3	-14.7	-14.9	-17.9	-22.2	-26.1	-26.1	-22.8	-19	-14.7	-12.5	-14.5	-16	-15.2	-17.7	-21.4	-21.5	-20.5	-21.5	-21.7	
Downstream SNR	31.9	25.5	24	30.3	30.8	34.9	34.9	32.3	28.3	25.5	25.5	28.4	31.1	35.5	36.6	34.3	33.3	34.9	32.9	28.7	29.8	30.6	29.7	29.7	
Upstream Tx Power	43.8					46.5							46						43.5						
Upstream SNR CM	34.6					33.6							36.2						36.6						
Upstream Rx Power	0					0							0						0						
US RX/WO Padding	0					0							0						0						
Upstream SNR Ch	34.6					33.7							36.4						36.7						
Upstream Ranging	4 (Success)					4 (Success)							4 (Success)						4 (Success)						

Figure 21. Most of the downstream SC-QAM signals have low signal level and degraded RxMER, indicated in red shaded boxes. The upstream was relatively unaffected (courtesy of Comcast).

Technicians went to the subscriber location and were able to find and fix the problem without having to enter the premises. ***Figure 22*** shows the coax jacket, which had been damaged by abrasion from the electrical service drop. The damaged coax jacket allowed water to enter the cable and travel inside of the cable all the way to the ground block. ***Figure 23*** shows water coming out of the connector at the ground block end of the drop.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Figure 22. Damaged coax jacket where water was able to enter the cable.

Figure 23. Water coming out of the end of the connector at the ground block.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

The fix was to replace the subscriber drop from the tap to the ground block. ***Figure 24*** shows the FBC screen shot after the new drop was installed, and ***Figure 25*** the post-repair SC-QAM performance.

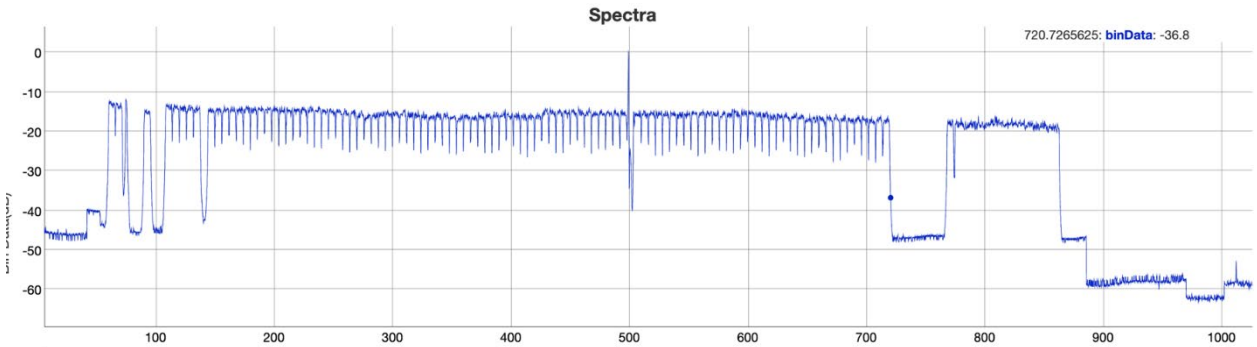

Figure 24. FBC response after drop cable was replaced from the tap to the ground block (courtesy of Comcast).

Device Health																									
Registration State	5 (Online)																								
Down Rx Power	1	1	0.9	1.2	1	1	1	0.9	0.7	0.9	0.5	0.9	1	1	1	0.9	0.7	0.9	1	1.2	1	0.7	0.7	0.4	
Downstream SNR	40.3	40.9	40.9	40.9	40.3	40.9	40.3	40.9	40.3	40.9	40.3	40.3	40.9	40.9	40.9	40.3	40.9	40.9	40.9	40.3	40.3	40.9	40.9	40.3	
Upstream Tx Power	39.8						40.3						40.5						40.3						
Upstream SNR CM	34.8						35.7						36.5						36.6						
Upstream Rx Power	0						-0.1						-0.1						-0.2						
US RX/WO Padding	0						-0.1						-0.1						-0.2						
Upstream SNR Ch	34.6						35.7						36.5						36.6						
Upstream Ranging	4 (Success)						4 (Success)						4 (Success)						4 (Success)						

Figure 25. Signal performance after the drop was replaced (courtesy of Comcast).

Additional discussion about water-soaked cable can be found in Section 7.4.

5.1.2. Localizing a problem to a specific drop

A problem was detected at Subscriber A: The OFDM modulation profile was limited to 64-QAM, but was expected to be 2048-QAM or better.

The OFDM signal in this 860 MHz HFC network is from 774 MHz to 864 MHz, with an exclusion band configured – 790 MHz to 820 MHz – to avoid ingress from the European 800 MHz 4G/LTE band.

Using the cable modem's built-in FBC function (port 8080), strong ingress was detected at all 5G and LTE frequencies in the area, as shown in ***Figure 26***.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

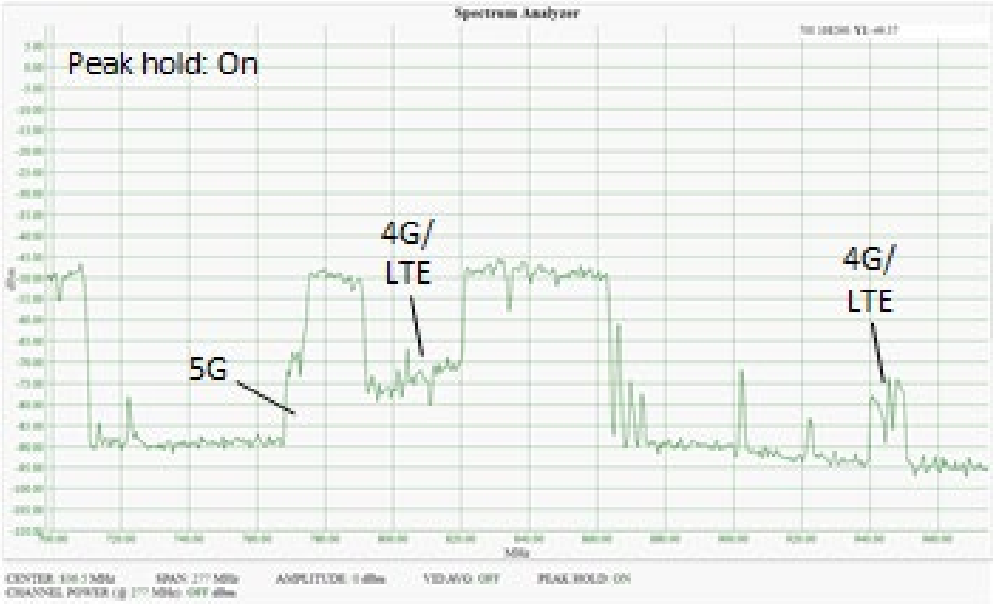

Figure 26. Subscriber A's FBC showing 4G/LTE and 5G ingress (courtesy of Telia Norge).

Looking up the neighboring address (Subscriber B) and using FBC in that cable modem (***Figure 27***), no ingress is to be seen.

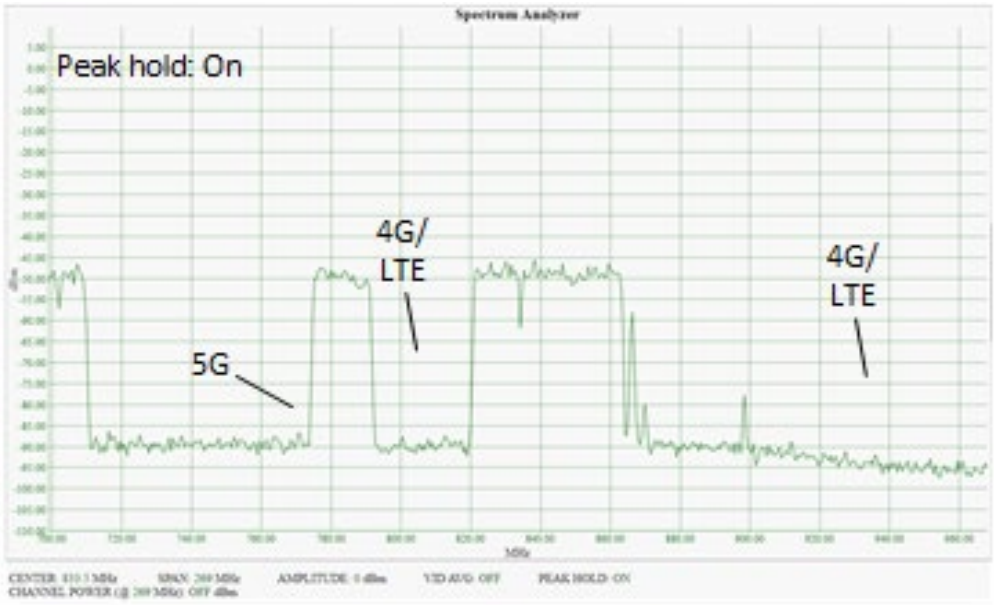

Figure 27. Subscriber B's FBC, showing no 4G/LTE or 5G ingress (courtesy of Telia Norge).

It can now easily be determined that the root cause of the problem is related to the drop cable and/or house internal network at Subscriber A's premises.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Checking the location of nearby base stations (***Figure 28***), it turns out that Subscriber A is located approximately 420 meters (~1380 feet) from a cell site that is operating on the 700, 800 and 900 MHz bands.

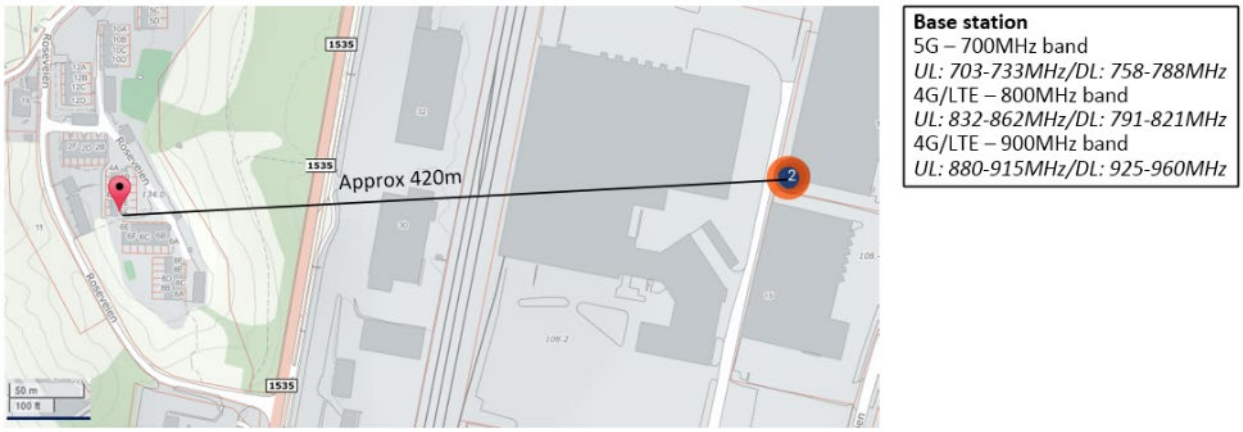

Figure 28. Location of cell site near the affected subscriber drop.

5.1.3. FBC Analysis and Fault Location Example

In this example a standing wave was detected that impacting a large part of a node's service area. This problem could clearly be seen in the FBC plots as shown in the traces on the right-hand side of ***Figure 29*** and was impacting all subscribers downstream of amplifier [1]. Modems that were being fed by a different distribution leg of upstream amplifier [2] did not show the impairment as can be seen in the FBC plot on the left. This analysis immediately isolates the problem to output connections coming from amplifier [1], the trunk output of amplifier [2] connecting to amplifier [1], or a cable fault between the two amplifiers.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

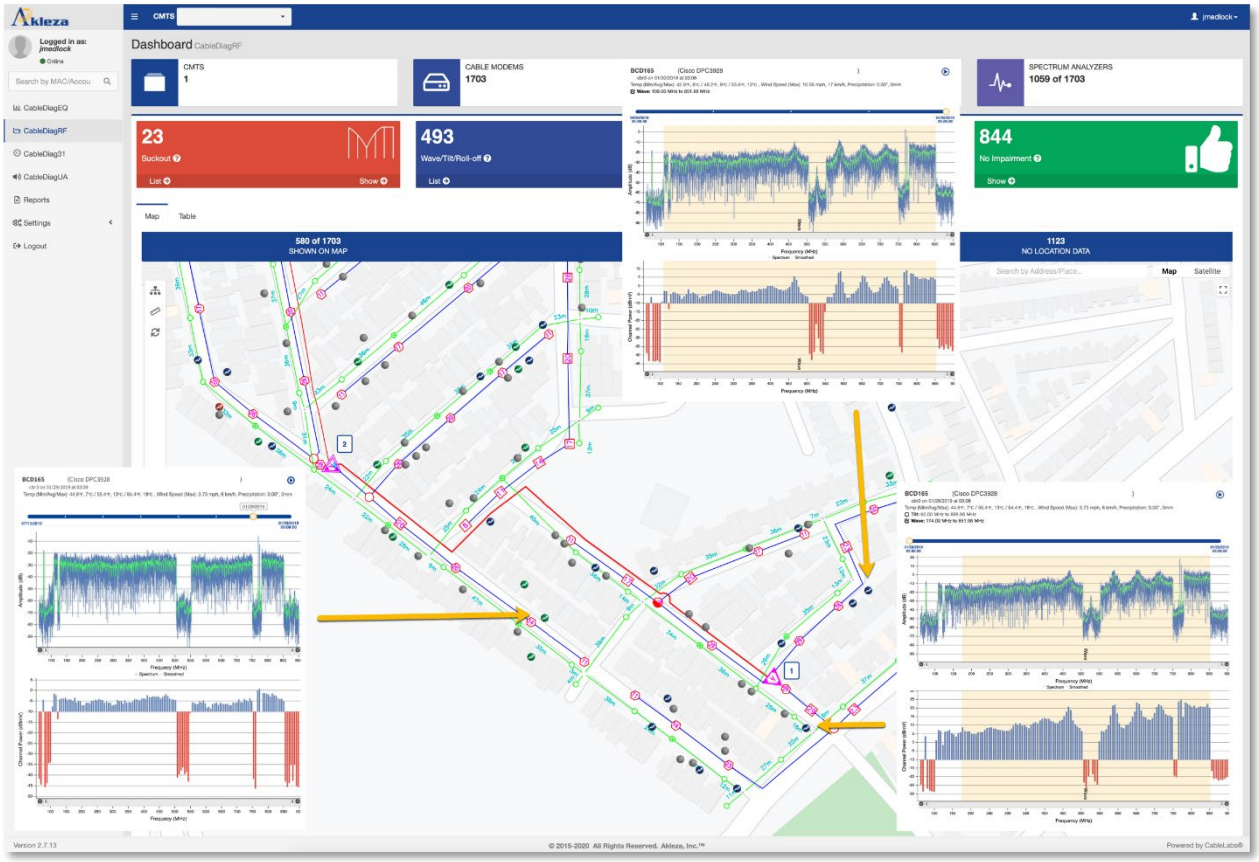

Figure 29. Example of using FBC to isolate a standing wave fault (courtesy of Akleza).

The technicians first checked amplifier [1] and its output connections. When the amplifier was opened, water poured out indicating a problem with the enclosure seal. Additionally, the internals of the amplifier showed corrosion as can be seen in ***Figure 30***.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Figure 30. Amplifier [1] containing water and showing corrosion (courtesy of Akleza).

Given the amount of damage to the amplifier, it was replaced, and the cable modems rescanned. This did not correct the problem indicating that the fault causing the standing wave was upstream of amplifier [1]. A field meter attached to the input side of the amplifier was used to verify this analysis and showed the problem could be seen in the signal coming in from upstream amplifier [2] (***Figure 31***).

The fault must therefore be with upstream amplifier [2] or its trunk output as it was already determined that the fault could not be seen on either of the amplifier's auxilliary distribution outputs.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

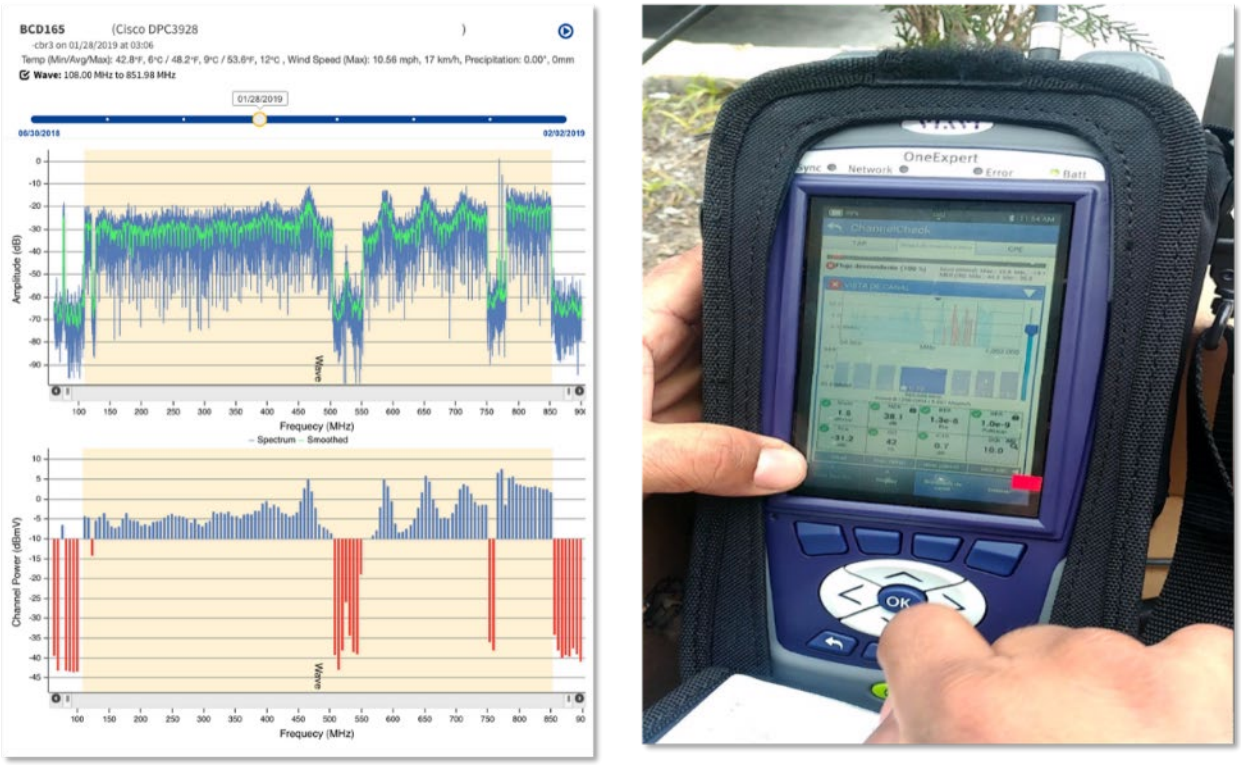

Figure 31. Fault still visible after replacement of amplifier [1] (courtesy of Akleza).

Verifying the signal at the output test port for the trunk connection did not show any standing wave meaning that the problem had to be with the output connector itself or the cable. When the output connection was inspected it was noticed that the connector showed signs of corrosion as well as the center conductor being cut too short, and therefore not making good contact internally (***Figure 32***). Corrorision and badly installed connectors are common causes of impedance mismatches in the cable plant and can cause standing wave spectrum faults.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Figure 32. Amplifier [2] with corroded connector (courtesy of Akleza).

Once the output connector was replaced, the cable modems were rescanned and showed that the standing wave fault had been fixed. ***Figure 33*** shows the resulting FBC plot from one of the cable modems after the fault was corrected.

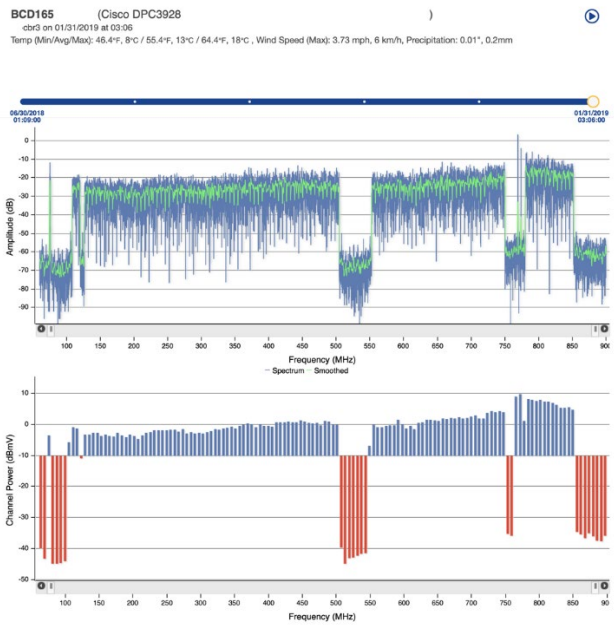

Figure 33. FBC trace after faulty connector replaced (courtesy of Akleza).

© 2020 SCTE•ISBE and NCTA. All rights reserved.

This example shows how analyzing FBC data collected remotely from cable modems within the network can quickly be used to identify customer service faults and quickly triangulate the fault location based on the FBC response from multiple devices.

6. How to retrieve and Display FBC Data

6.1. FBC Data Collection

In DOCSIS 3.0 the configuration and collection of FBC data uses SNMP requests to a cable modem supporting FBC. The PNM Best Practices: HFC Networks (DOCSIS 3.0) guide [Ref. 4] describes the high-level functionality while the SNMP MIB objects are defined in the DOCS-IF3-MIB.[3]

DOCSIS 3.1 introduced a new set of requirements on the cable modem related to the collection and reporting of PNM data as described in Section 9 of the DOCSIS 3.1 Physical Layer Specification [Ref. 5], and in PNM Best Practices Primer: HFC Networks (DOCSIS® 3.1) [Ref. 8]. DOCSIS 3.1 also introduced a new bulk-data transfer mechanism that uses the trivial file transfer protocol (TFTP) to upload PNM data to a destination TFTP server. Configuration of the PNM test execution, file storage, and TFTP destination use SNMP as defined in [Ref. 3] and CCAP Operations Support System Interface (OSSI) Specifications [Ref. 6].

While the DOCSIS 3.1 bulk-data transfer mechanism supports the collection of FBC data, this is only supported by DOCSIS 3.1 cable modems. The DOCSIS 3.0 SNMP-only mechanism is, however, supported by both DOCSIS 3.0 and 3.1 modems and functionally provides the same capability so can be used as a single method across both cable modem types. This section covers the use of the DOCSIS 3.0 SNMP configuration and retrieval mechanism. For more information on the DOCSIS 3.1 bulk-data transfer mechanism refer to [Ref. 3] and the DOCS-PNM-MIB.

Commercial FBC data collection, analysis, and display products are generally available in the market from PNM vendors. The following information is provided on how to configure, retrieve, and plot FBC data for those looking to experiment with and understand what is possible with that data. Because capturing spectrum information requires SNMP read/write access to the cable modems, access using a locally attached workstation is unlikely. Typically, an FBC solution is deployed within the cable operator's operations or back office organization and must deal with a number of elements including security and data storage. A high resolution, full downstream spectrum capture can generate 200 kB to 300 kB of data that is streamed back from the cable modem. Deploying a system-wide solution therefore requires careful engineering as well as suitable resources to handle the data collection and storage requirements.

In the provided examples the freely available Net-SNMP tools are used which can be installed on most operating systems. For specific instructions on installing and using Net-SNMP for a particular platform visit the Net-SNMP website at www.net-snmp.org. Any SNMP community string or IP addresses included in this paper are simply examples and should be updated to match your own environment. Some Python-based scripts have also been provided to assist in the collection and display of the FBC data. These are provided purely for informational purposes and should not be considered production-level code. **Figure** 34 shows the DOCS-IF3-MIB objects that will be used to configure and retrieve the FBC data from the cable modem.

[3] The CableLabs MIB repository is here: http://mibs.cablelabs.com/MIBs/DOCSIS/

© 2020 SCTE•ISBE and NCTA. All rights reserved.

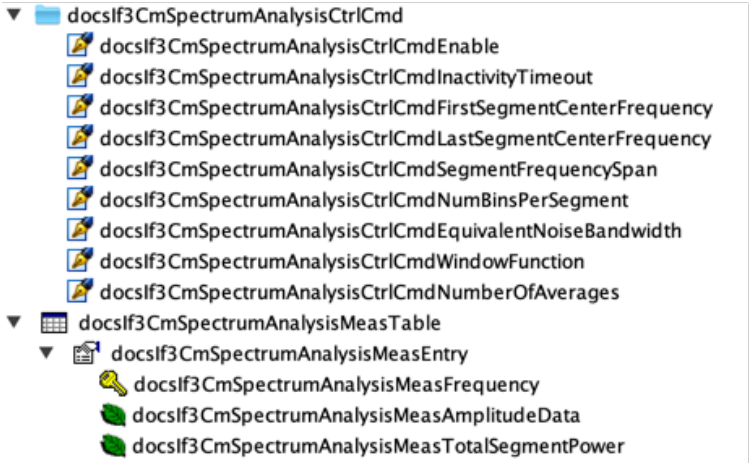

Figure 34. IF3-MIB spectrum capture objects

While in general all DOCSIS 3.0 and 3.1 cable modems should be capable of spectrum capture, some early DOCSIS 3.0 cable modems running older versions of firmware may not support the capability. In order to first determine if a cable modem supports FBC, a simple SNMP read operation on the docsIf3CmSpectrumAnalysisCtrlCmdEnable object can be performed. If the device supports FBC, this object will return a value, while a device that does not support the function will return an SNMP No Such Object error meaning that the cable modem firmware does not support the DOCS-IF3-MIB FBC objects.

This example shows a response from a cable modem that supports FBC.

```
$ snmpget -v2c -c public 10.60.0.7 docsIf3CmSpectrumAnalysisCtrlCmdEnable.0
DOCS-IF3-MIB::docsIf3CmSpectrumAnalysisCtrlCmdEnable.0 = INTEGER: false(2)
```

This example shows the response from a cable modem that does not support FBC.

```
$ snmpget -v2c -c public 10.60.0.17 docsIf3CmSpectrumAnalysisCtrlCmdEnable.0
DOCS-IF3-MIB::docsIf3CmSpectrumAnalysisCtrlCmdEnable.0 = No Such Object available on this agent at this OID
```

Instructing the cable modem to collect FBC data and then retrieving the data is a two-step process. First the `docsIf3CmSpectrumAnalysisCtrlCmd` objects need to be set to values describing the data capture you want, and then the results are read from the `docsIf3CmSpectrumAnalysisMeasTable`. Again, depending upon the vintage of the cable modem and the functionality supported by its firmware, not all configurations may be possible.

To understand the configuration of the spectrum capture, you first need to consider how much of the spectrum you want to capture, and the resolution of the captured data. Between the start (`docsIf3CmSpectrumAnalysisCtrlCmdFirstSegmentCenterFrequency`) and end (`docsIf3CmSpectrumAnalysisCtrlCmdLastSegmentCenterFrequency`) points of the desired spectrum capture, you define the width of a segment (`docsIf3CmSpectrumAnalysisCtrlCmdSegmentFrequencySpan`) and then how many samples or bins (`docsIf3CmSpectrumAnalysisCtrlCmdNumBinsPerSegment`) you want measured within that segment. The configuration of these parameter defines how much data is going to be collected and needs to be read back from the cable modem. The greater the number of bins the higher the spectral resolution, however, this will generate more data that must be retrieved.

For example, if you request a capture of the full downstream spectrum, from, say, 54 MHz to 1002 MHz, using a segment frequency span of 6 MHz, and 256 bins per segment, you would generate 40,192 data points at a resolution of 23 kHz per point. Reduce the number of bins to 64, and you would now only

© 2020 SCTE•ISBE and NCTA. All rights reserved.

have 10,048 data points with a resolution of 94 kHz per point. Depending upon how you intend to use the data and the resources available to capture and store the data, you can adjust these configuration parameters accordingly.

To initiate a spectrum capture, you first must set the configuration parameters and the enable flag. **Figure** 35 shows how to configure a high resolution full downstream data collection as just described.

```
$ snmpset -v2c -c public 10.30.0.12 \
docsIf3CmSpectrumAnalysisCtrlCmdFirstSegmentCenterFrequency.0 u 57000000 \
docsIf3CmSpectrumAnalysisCtrlCmdLastSegmentCenterFrequency.0 u 999000000 \
docsIf3CmSpectrumAnalysisCtrlCmdSegmentFrequencySpan.0 u 6000000 \
docsIf3CmSpectrumAnalysisCtrlCmdNumBinsPerSegment.0 u 256 \
docsIf3CmSpectrumAnalysisCtrlCmdEnable.0 i 1
```

Figure 35. Configuration example for high resolution downstream data collection.

The command in **Figure** 35 sets the span width to 6 MHz, the start center frequency to 57 MHz, and the end center frequency to 999 MHz. Setting the enable value to true (1) signals the cable modem to start its spectrum capture. Using the 6 MHz span width additionally allows the spans to be aligned to standard channel frequencies whose power is also measured during the spectrum capture.

With the spectrum capture now enabled, the spectrum data can be retrieved by doing a snmpwalk of the `docsIf31CmSpectrumAnalysisMeasAmplitudeData`. This will return an SNMP table row for each frequency span as shown in **Figure** 36.

```
$ snmpwalk -v2c -c public 10.30.0.12 docsIf3CmSpectrumAnalysisMeasAmplitudeData
DOCS-IF3-MIB::docsIf3CmSpectrumAnalysisMeasAmplitudeData.57000000 = Hex-STRING:
03 65 C0 40 00 5B 8D 80 00 00 01 00 00 00 5B 8D
00 00 5B 8D E6 D6 E6 EA E6 9D E6 43 E6 11 E6 19
E5 A6 E4 56 E3 B8 E4 59 E5 B8 E6 41 E6 5C E6 2B
: SOME DATA ROWS REMOVED TO SAVE SPACE
E6 C7 E6 B0 E6 7B E6 4B E6 06 E5 73 E4 8D E3 77
E0 F5 E0 8E E1 AC E3 41 E3 D1 E3 92 E3 4C E2 52
E1 47 E2 1C
:
DOCS-IF3-MIB::docsIf3CmSpectrumAnalysisMeasAmplitudeData.999000000 = Hex-STRING:
3B 8B 87 C0 00 5B 8D 80 00 00 01 00 00 00 5B 8D
00 00 5B 8D E6 28 E4 0A E1 FB E2 9D E5 59 E6 59
E6 86 E6 AB E6 8E E5 FC E4 C9 E2 EE DE 32 DE 5F
: SOME DATA ROWS REMOVED TO SAVE SPACE
E8 87 E8 8F E8 26 E7 B9 E7 2F E6 E3 E6 C5 E6 61
E5 3E E4 55 E5 31 E7 45 E7 FC E8 2F E7 D3 E7 0C
E5 7A E2 41
```

Figure 36. Returned SNMP table row for each frequency span.

The first 20 bytes of each rows data consists of five integers (4 bytes) as follows:

```
 4 bytes: CenterFreq
          The center frequency of the span.
  4 bytes: FreqSpan
          The width in Hz of the span.
  4 bytes: NumberOfBins
          The number of data points or bins that compose the
          spectral data. The leftmost bin corresponds to the
          lower band edge, the rightmost bin corresponds to the
          upper band edge, and the middle bin center is aligned
          with the center frequency of the analysis span.
  4 bytes: BinSpacing
          The frequency separation between adjacent bin
```

© 2020 SCTE•ISBE and NCTA. All rights reserved.

```
                 centers. It is derived from the frequency span and
                 the number of bins or data points.
                 The bin spacing is computed as:

                   BinSpacing = FrequencySpan/(NumberOfBins - 1)

                 The larger the number of bins the finer the resolution.
4 bytes: ResolutionBW
                 The resolution bandwidth or equivalent noise
                 bandwidth of each bin. If spectral windowing is used
                 (based on vendor implementation), the bin spacing and
                 resolution bandwidth would not generally be the same.
```

Each remaining two-byte data pair represents a bin amplitude in units of 0.01 dB. The bin amplitude data is in two's complement format so must be translated into a decimal value. There are a number of ways to convert two's complement data to decimal, but to simplify, we first convert from hexadecimal to decimal. Then, if the value is greater than 32767, it represents a negative number so we subtract 65535; otherwise, use the initially converted value. Divide the result by 100 to get the amplitude bin in dB. For example:

```
E6D6 in decimal is 59094
As 59094 > 32767 then bin value = 59094 – 65535 = -6441
Bin Amplitude in dB = -6441 / 100 = -64.41 dB
```

Using the example data above, the first row would decode as:

```
center frequency: 0365C040 = 57000000 Hz
frequency span: 005B8D80 = 6000000 Hz
number of bins: 00000100 = 256
bin spacing: 00005B8D: 23437 Hz
resolution bandwidth: 00005B8D = 23437 Hz
Bin 0: E6D6 = -64.41 dB
Bin 1: E6EA = -64.21 dB
Bin 2: E69D = -64.98 dB
:
Bin 255: EC1C = -50.91 dB
```

Given the center frequency, the number of bins, and the bin spacing, the frequency of each bin can be calculated

```
Frequency = center frequency – (number of bins / 2 * bin spacing) + (bin number *
bin spacing)
```

Using this formula, the frequency for the above example bins would be:

```
Bin 0: 54000064 Hz
Bin 1: 54023501 Hz
Bin 2: 54046938 Hz
:
Bin 255: 59976499 Hz
```

After decoding each of the `docsIf3CmSpectrumAnalysisMeasAmplitudeData` rows into their frequency and bin amplitude parts, you now have a list of frequencies and amplitudes that can be plotted to show the FBC spectrum.

In order to simplify the retrieval, decoding, the Appendix contains Python code listings of scripts that can be used to collect and display FBC data. The output of the getFbcData.py script is a comma separated values (CSV) file containing frequency and amplitude columns. This file can be directly imported into Excel and a chart created. **Figure** 37 shows an example Microsoft Excel chart using this imported data.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

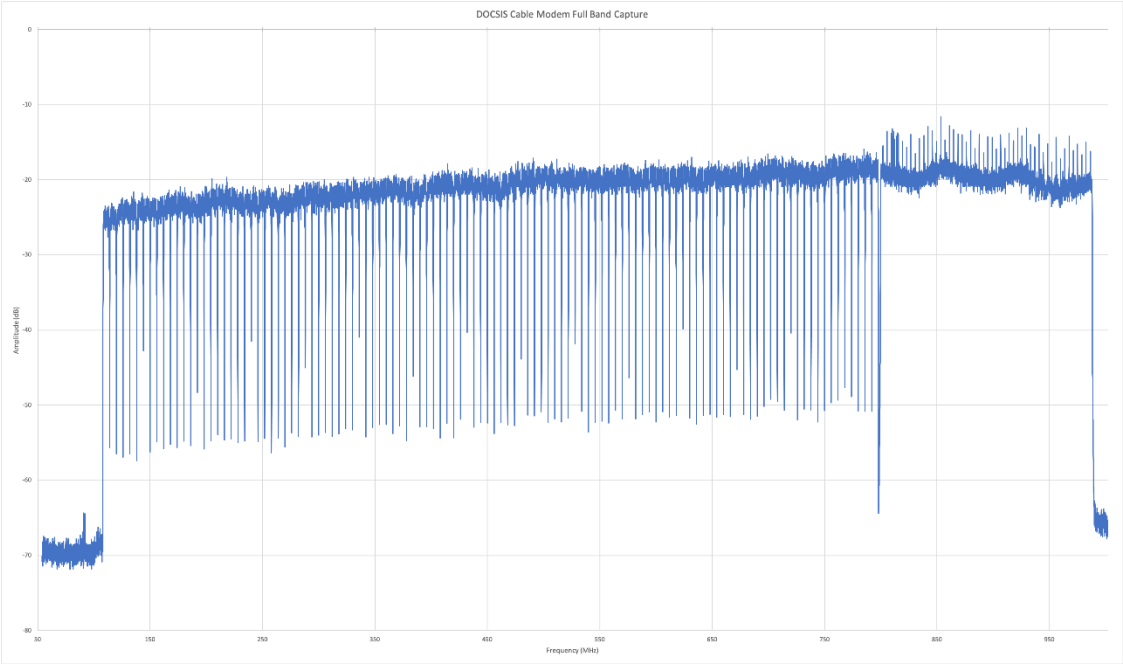

Figure 37. FBC plot using Microsoft Excel (courtesy of Akleza).

The Python script showFbcData.py reads a previously saved FBC CSV file and displays a plot using the Python Plotly package. **Figure** 38 shows the same FBC data displayed using this script.

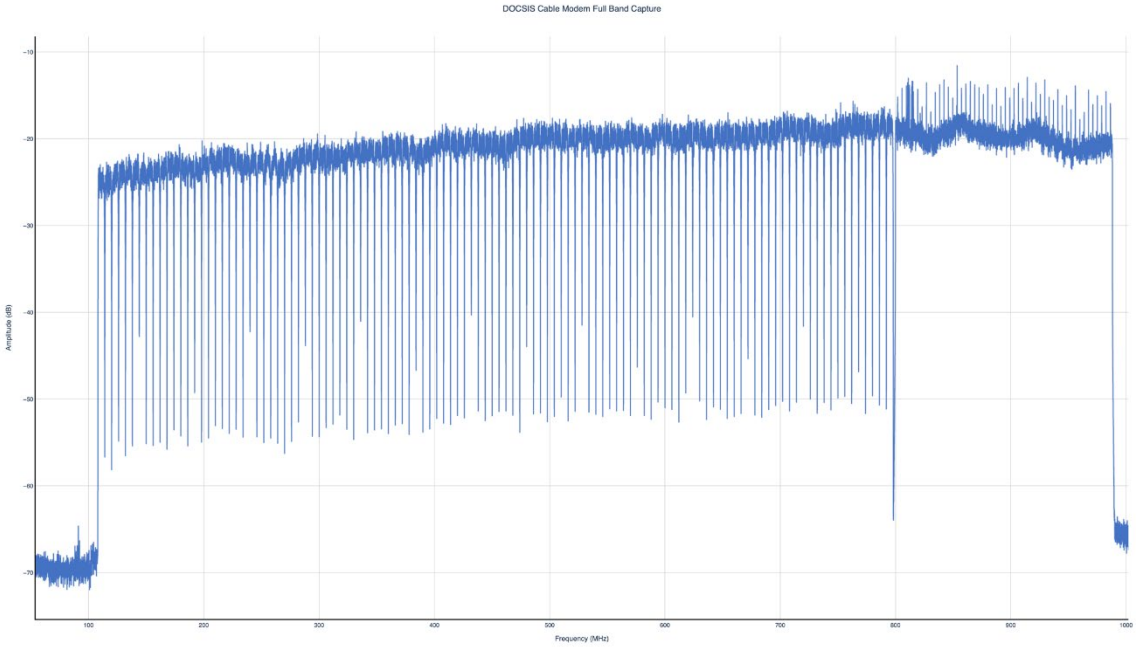

Figure 38. FBC plot generated using example Python scripts (courtesy of Akleza).

As shown in **Figure** 34 there are a number of configuration parameters that can be used to control the extents and resolution of the FBC function on the cable modem. Configuration parameters are also

© 2020 SCTE•ISBE and NCTA. All rights reserved.

available to control the spectral windowing function and the number of captures to be averaged during the spectrum capture.

The DOCS-PNM-MIB defines a number of windowing filters to smooth out spectral leakage problems in the underlying capture mechanism. While a number of window functions are specified, not all cable modem implementations support all of them but most do support the Hanning window which is commonly used by setting the `docsIf3CmSpectrumAnalysisCtrlCmdWindowFunction` to `hann(1)`.

Averaging is an important configuration option to help in smoothing the instantaneous capture of the underlying ADC within the FBC process. For example, **Figure** 39 shows the result of a capture with no averaging performed.

```
$ snmpset -v2c -c public 10.30.0.8 \
docsIf3CmSpectrumAnalysisCtrlCmdFirstSegmentCenterFrequency.0 u 57000000 \
docsIf3CmSpectrumAnalysisCtrlCmdLastSegmentCenterFrequency.0 u 999000000 \
docsIf3CmSpectrumAnalysisCtrlCmdSegmentFrequencySpan.0 u 6000000 \
docsIf3CmSpectrumAnalysisCtrlCmdNumBinsPerSegment.0 u 256 \
docsIf3CmSpectrumAnalysisCtrlCmdWindowFunction.0 i 1 \
docsIf3CmSpectrumAnalysisCtrlCmdNumberOfAverages.0 u 1 \
docsIf3CmSpectrumAnalysisCtrlCmdEnable.0 i 1
```

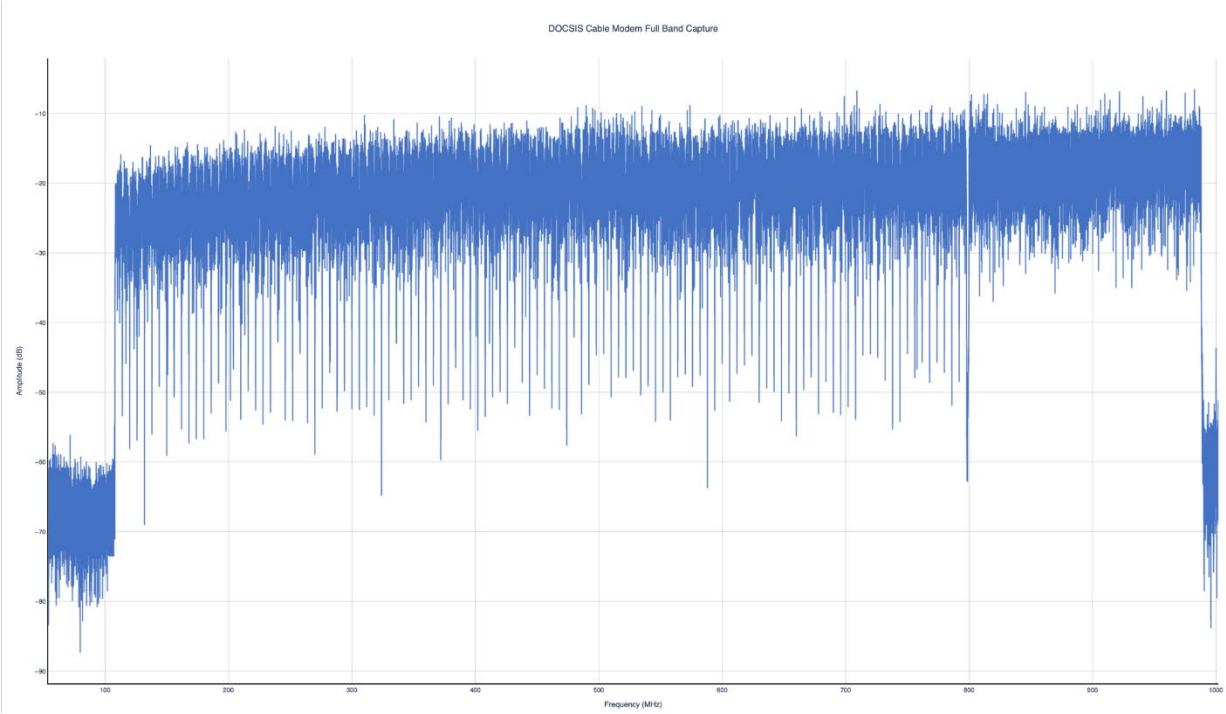

Figure 39. FBC plot with no averaging (courtesy of Akleza).

Figure 40 shows a capture where the `docsIf3CmSpectrumAnalysisCtrlCmdNumberOfAverages` was set to 32. Now you can more clearly see details such as the pilots and PLC in the OFDM channel which are lost in **Figure** 39.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

```
$ snmpset -v2c -c public 10.30.0.8 \
docsIf3CmSpectrumAnalysisCtrlCmdFirstSegmentCenterFrequency.0 u 57000000 \
docsIf3CmSpectrumAnalysisCtrlCmdLastSegmentCenterFrequency.0 u 999000000 \
docsIf3CmSpectrumAnalysisCtrlCmdSegmentFrequencySpan.0 u 6000000 \
docsIf3CmSpectrumAnalysisCtrlCmdNumBinsPerSegment.0 u 256 \
docsIf3CmSpectrumAnalysisCtrlCmdWindowFunction.0 i 1 \
docsIf3CmSpectrumAnalysisCtrlCmdNumberOfAverages.0 u 32 \
docsIf3CmSpectrumAnalysisCtrlCmdEnable.0 i 1
```

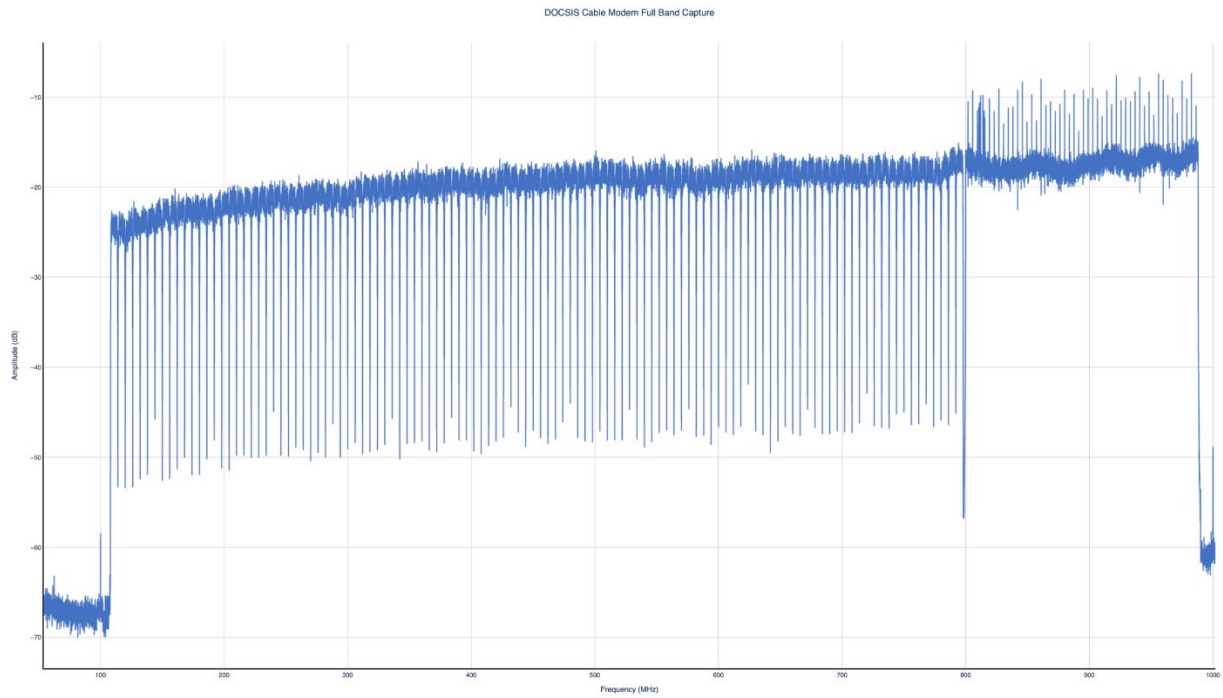

Figure 40. FBC plot with 32 averages (courtesy of Akleza).

Unfortunately, older cable modems do not fully support averaging, some supporting a smaller number of averages, and some none at all. In these cases, the initial set of the `docsIf3CmSpectrumAnalysisCtrlCmdNumberOfAverages` object will fail with an SNMP error as follows:

```
Reason: inconsistentValue (The set value is illegal or unsupported in some way)
Failed object: DOCS-IF3-MIB::docsIf3CmSpectrumAnalysisCtrlCmdNumberOfAverages.0
```

When this occurs the polling application will have to make multiple requests to retrieve a number of samples and then implement a running average over these samples.

With both averaging and collection of high-resolution captures, significant detail can be seen. **Figure** 41 shows the same capture as above but zoomed into see the detail of the SC-QAM signals and the start of the OFDM signal with its pilots and PLC.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

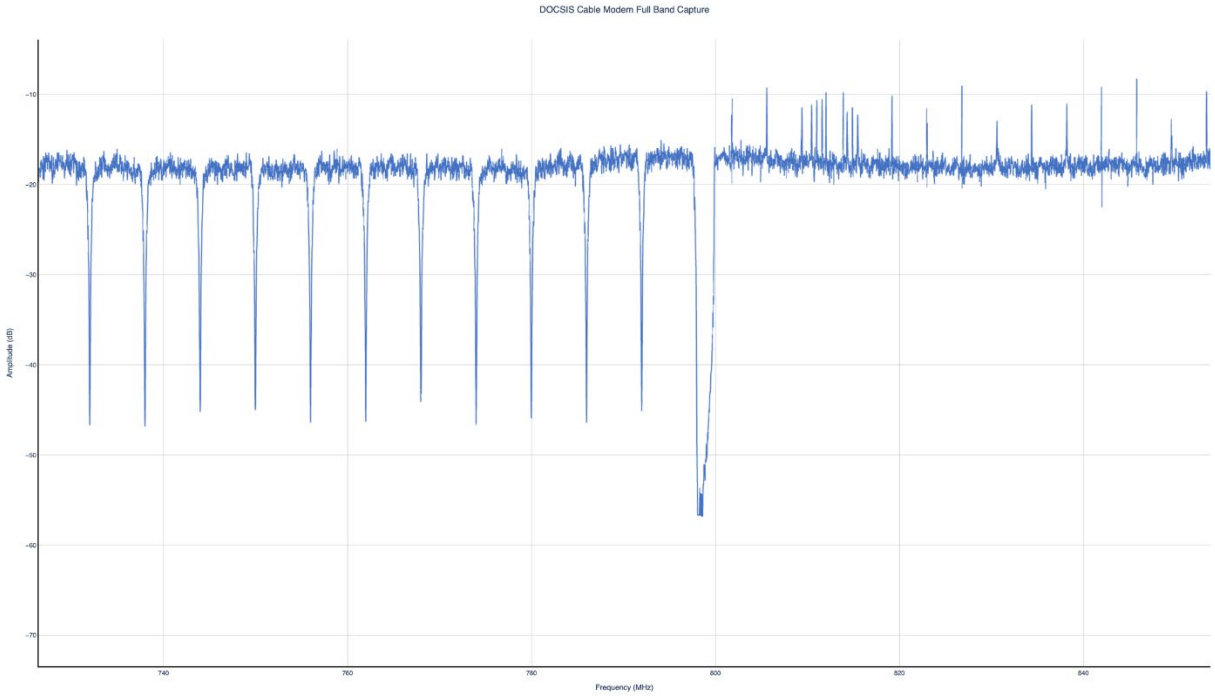

Figure 41. Zoomed view of high resolution and averaged FBC (courtesy of Akleza).

© 2020 SCTE•ISBE and NCTA. All rights reserved.

7. Advanced FBC Applications

7.1. Estimating Distances with High Accuracy

Because of a large potential bandwidth associated with an FBC spectrum, the ripples or waves in the magnitude plot can be analyzed to produce very accurate distance estimates. A signal captured in a narrow band can only produce inaccurate distance measurements. One method that has been developed in the CableLabs PNM Working Group is to process spectral data with an inverse discrete Fourier transform, using the FBC response for real coefficients and all zeroes for the imaginary coefficients. If a broadband signal is transformed, this method produces a highly accurate time response, and a magnitude response with decent and predictable results.

It is useful to examine exactly how delayed signals arrive at the cable modem or time domain reflectometer (TDR), and how and where they can be observed using, for example, high impedance probes. **Figure** 42 has two diagrams showing how reflections are generated on a cable line, one with a single reflection and one with two reflections. The cable lines are blue and X marks the locations of impedance mismatches R, RA, and RB. Each impedance mismatch in this example causes a 20% reflection ($S_{11} = S_{22} = 0.2$). The horizontal lines are signals going downstream to the right and diagonal lines are signals going upstream to the left. The strength of the signals in volts for each cable segment is labeled in red and the coax is assumed to have no cable loss. The TDR impulse response plot is shown on the left, and an FBC impulse response received downstream is shown on the right. Upstream and downstream responses can also be observed by high impedance probes, placed as illustrated.

For the single reflection case, a 20% signal is reflected back from point R and is observed at probe 1, but no delayed copy of the signal appears downstream (probe 2). However, probe 2 does observe that the downstream signal is weaker than it should have been (0.8 instead of 1.0). In other words, FBC on a cable modem is effectively blind to a single reflection caused by a single impedance mismatch.

For the two-reflection case, signals bounce back and forth between reflection points RA and RB infinitely, although generally only the first few recursions can be observed before the signal is too weak to be seen. A ripple in the frequency domain is equivalent to one or more impulses in the time domain. Thus, when a ripple in the frequency domain is observed, you know you have an echo tunnel (distance between RA and RB), but you don't know the locations of the start point or stop point. However, you can determine an exact length from an exact time delay obtained by an inverse Fourier transform. **Figure** 43 shows water damage that created one end of an echo tunnel, and the other end of the tunnel was caused by a seizure screw not being tightened on a terminator.

Additional information about reflection types can be found in [Ref. 7].

© 2020 SCTE•ISBE and NCTA. All rights reserved.

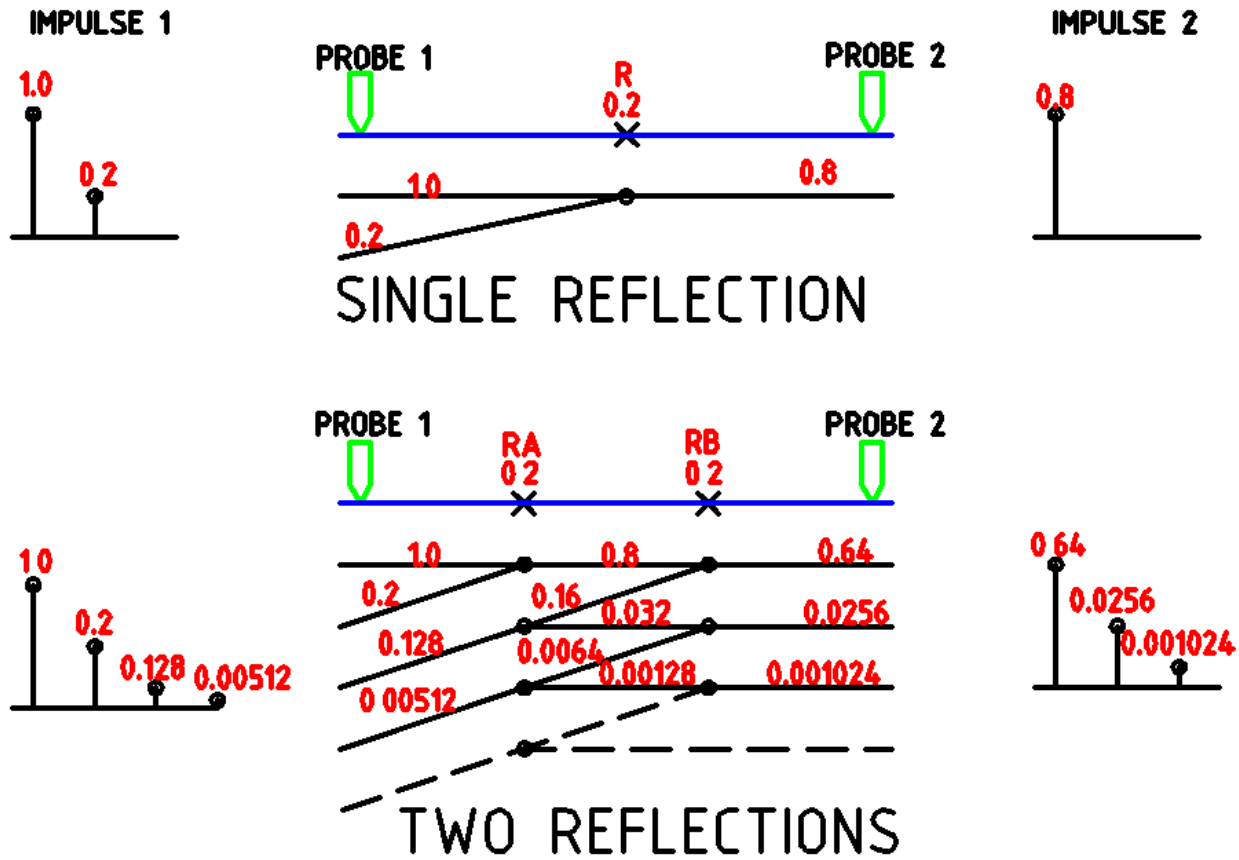

Figure 42. Diagrams showing what is observed at two points on a cable line for the one- and two-reflection cases. The inpulse responses on the right can be observed by the FBC and the inpulse responses can be observed by an active or passive TDR.

Figure 43. Damaged hardline coax that was at one end of an echo tunnel; the other end was a loose seizure screw on a chassis terminator installed in an end-of-line tap. Further

© 2020 SCTE•ISBE and NCTA. All rights reserved.

complicating things: The damaged cable was submersed in water. Courtesy of CableLabs.

7.2. Drop Cable Testing

A simple test that can be done on drop cable to verify that it is working well is to disconnect one end, say at the ground block, and test the drop cable from the tap with a TDR. The TDR impulse response should reveal the open drop cable with only a few dB of attenuation associated with the drop cable. Any other response indicates a bad drop cable. This method can be performed with a conventional metallic TDR or with a passive TDR.[4]

7.3. Using FBC to View Upstream Noise

The FBC's tuning range includes the upstream band. The upstream band is of interest to capture for much the same reasons as the downstream band; just as impairments add energy that interferes with reception of downstream signals (see Section 3), energy can be added that interferes with the reception of upstream signals. Assume that somewhere in the drop or house wiring is a shield break that allows electrical noise traveling on the outside of the coax to gain entry to the coax wiring. Once the noise gains entry, it travels in both directions – toward the CPE and toward the headend or hub – the latter where it can cause interference to other upstream signals at the CMTS receiver. The same interference can be detected by terminal equipment located in the home, identifying the home where the ingress entered the cable plant.

How strongly the ingress enters the plant, compared to the upstream transmission, will determine the ingress-to-signal ratio at the upstream receiver. Also, where the ingress enters the plant, in terms of insertion loss to-and-from the cable modem, will determine how the ingress-to-signal ratio will appear at the F-connector of the cable modem. Even if there are no filters or active components in the path between the ingress point and the cable modem, the ingress-to-signal ratio will be lower at the cable modem F-connector than at the CMTS upstream receiver, and will be lower by at least twice the insertion loss of the path from the cable modem to the ingress point.

An additional consideration is that upstream signals can have levels in the range of +17 dBmV/1.6 MHz to +53 dBmV/1.6 MHz, generally; for comparison, downstream signal levels can be in the range of -10 dBmV to +15 dBmV per 6 MHz channel. In some cases the cable modem's transmitted upstream energy can be significantly greater than it is receiving in the downstream. To be useful in locating ingress it will generally be necessary to capture upstream ingress when upstream transmissions are not occurring at the same frequency. This is because often an impairing ingress has smaller PSD than the transmitted signal, at the cable modem, and will be obscured by the cable modem's own transmission if it is occurring at the same frequency as the ingress.

Capturing the upstream spectrum at the F-connector of the cable modem can help provide insight into troubleshooting, and lead to fixing the cause of the ingress. Since the ingress-to-signal ratio is generally already lower at the cable modem than at the upstream receiver, it is desired to capture the upstream spectrum without the stopband loss that would occur on the high-frequency port of a cable modem's

[4] Water damaged cable may not show up well unless the TDR has test energy in the UHF spectrum, which can usually be achieved by choosing a very narrow pulse width.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

internal diplex filter. Details of how this is facilitated in some cable modem implementations are beyond the scope of this paper.

7.4. Using FBC to Find Water-Soaked Coaxial Cable

Figure 44 is a frequency response of a coaxial cable that has water inside the jacket. It can be compared to **Figure** 45 which is caused by a standing wave created by a pair of separated impedance mismatches. Operational experience has shown that this water characteristic is a highly reliable indicator of the presence of water in coax, most typically in drop cable. But water responses have also been observed in hardline coax. If a coaxial cable is tested with a TDR in wide bandwidth mode (narrow pulse width), a nearby region of water damage can be localized. It has been observed to correct itself when the coax either dries out or the water inside is frozen hard, although its characteristic reappears when the frozen water thaws. Water gets inside the coax at abrasion points, hairline cracks, kinks, or at connectors. The rough non-periodic spectral response is caused by the non-uniform saturation of water-versus-distance over a section of the coaxial cable. Generally, a second characteristic accompanies the rough spectral response: higher attenuation at high downstream frequencies, as much as 15 dB to 25 dB (or more!). Upstream attenuation is typically only a few dB, but the high downstream attenuation often results in greatly reduced throughput and customer dissatisfaction. The adaptive equalizer in the cable modem can tolerate the rough spectral response, but loss of signal level results in data errors.

Relatively simple software currently exists to detect both types of impairments by their rapid variation of amplitude versus frequency, but these simple algorithms cannot distinguish water damage from standing waves.

A DSP algorithm is being developed where a spectral response is filtered, flattened and interpolated to remove high-level responses such as AGC pilot signals, and low responses such as vacant spectrum. Finally, an inverse Fourier transform produces an impulse response which is examined for dispersion. One or two narrow lines indicate a standing wave, and a dispersed time response indicates water. The dispersion can be enhanced by performing an autocorrelation function on the time response, improving detection. Another revealing characteristic is large spectral down-tilt caused by water attenuation. **Figure** 44 shows a response with water in time and frequency and **Figure** 45 shows the same data for a standing wave.

One simple method to measure dispersion is to measure the impulse response coefficients relative to the DC term, remove the two largest coefficients, and then remeasure the coefficients. A small drop after coefficient removal indicates a dispersed water response and a large drop indicates a large standing wave response. Another method is to take the ratio of the peak-to-average of the time coefficients, where a large peak-to-average indicates a standing wave, and a smaller peak-to-average ratio indicates a non-periodic water-caused wave. Note that it is possible for a cable to suffer both water and standing wave impairments at the same time. Likewise, it is possible for a cable to have a second standing wave frequency present.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

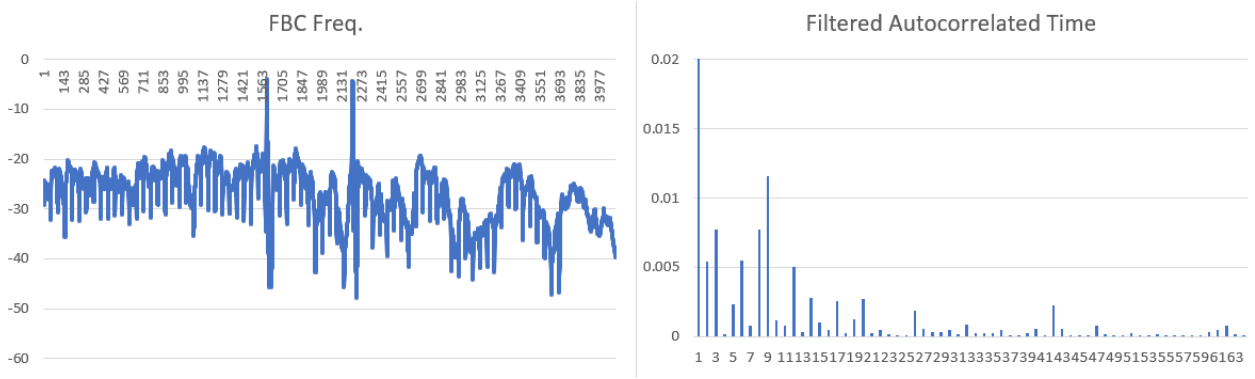

Figure 44. Water-soaked coax, FBC plot on left and impulse response on right. The impulse response is highly dispersed.

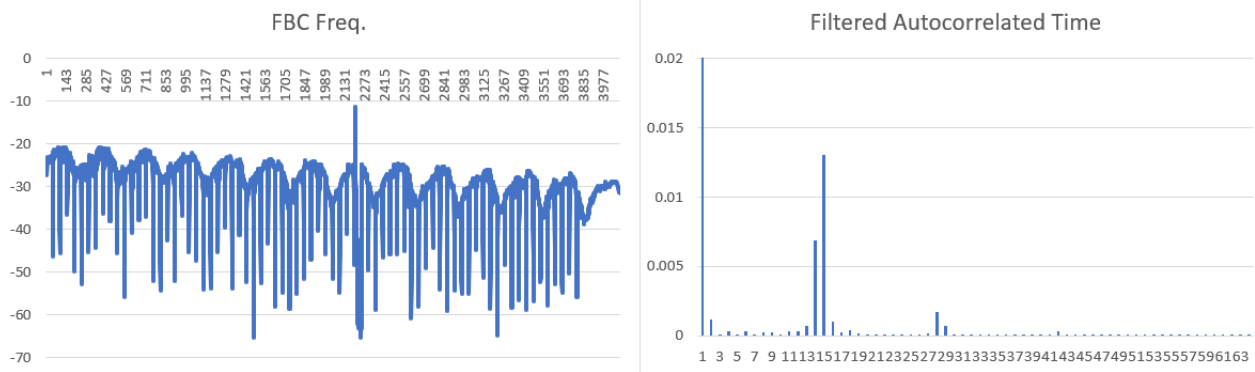

Figure 45. Coax with standing wave response. FBC plot is on left and impulse response is on right. The impulse response is not dispersed.

8. Impairment Detection

Detecting impairments from spectrum analysis data is simple but time consuming to do manually. Fortunately, there are methods that can assist with this problem. Three practical categories for addressing this problem effectively include:

- Simple magnitude and statistical methods followed up with manual inspection,
- Mathematical and statistical models to recognize impairments followed up with manual inspection, and
- Machine learning approaches that find and classify impairments, for either direct action or followed up with manual inspection.

Only operators will have numbers to compare between these methods, and so far we have not found any data being shared. We expect, however, that the first two methods will generally be slower than the third, based on a comparison of methods developed by CableLabs; and we expect that false positives and false negatives will decrease moving down this list. Further, because the purpose is to address the impairments, eventually someone will manually validate the results, before or during dispatch.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

However, it is important to mention that automating the first inspection of spectrum data can reduce the bulk of manual labor necessary. The speed of automated inspection may not be a critical factor, but rather the ability to do a reliable first inspection will save a large amount of manual work.

For example, consider 1000 results. If there are 10 impairments in 1000 samples, a manual process has to look at all 1000 samples to find them. An automated process might have 50% false positives and 10% false negatives, so might report 18 impairments. After looking at these 18 results manually, which is far faster than looking at 1000, nine impairments may be found. The net result is finding nine impairments by looking at 18 for a 50% efficiency, compared to finding 10 impairments by looking at 1000 for a 1% efficiency. While not all impairments are found due to the false negative rate, the efficiency is profound.

For some time, there have been DOCSIS® 3.0 anomaly detection methods available in the CableLabs Common Code Collection (C3). This method is a rule-based method that finds anomalies, identifies their types, and finds the frequencies they impact, all using rules, statistics, and traditional methods. CableLabs created a prototype which Comcast implemented and improved on, and that version is available for use by operators.

For DOCSIS 3.1, CableLabs offers ProOps as a platform for operators to test PNM methods, which includes a statistical method as well as the potential for a machine learning-based anomaly detection method. The latter is used for RxMER data today, but we are confident that it can be trained to work with spectrum data if operators wish to try this.

8.1. Impairment detection and automation

Automating FBC impairment analysis helps present the data in ways that are easy to understand and drive business decisions. Anomaly detection and classification algorithms are available through CableLabs or built into commercially available PNM tools. These algorithms detect and categorize the severity of the impairments at each FBC-capable cable modem in the network. In addition to the detection and severity categorization, the automation tools typically provide statistics and a list of modems with similar impairments grouped by geographic areas. This gives insight into the area of the HFC network that is of interest and has the potential to impact the customer experience of many subscribers.

For example, detected impairments are typically color coded by severity. Yellow for minor (less likely to be impacting) and red for major (more likely to be impacting). This enables the automation tool to assign a status of “red” to a modem that has one or more impairments identified, meeting the criteria for “red.” Subsequently it is easy to count and calculate the percentage of modems with a “red” status, either overall or by impairment. Combine the impairment severity information with HFC network topology information, and the automation tool will guide an engineer or network analyst to the HFC segment with the most issues identified.

The impairment algorithms use the FBC spectrum data, based on the bins, and calculate the power levels to represent the 6 MHz channels when required. The following is a brief description of the available impairment algorithms and their behavior:

Tilt – The condition where signal levels vary in a linear manner as the frequency increases. The variation can be low to high (positive tilt) or high to low (negative tilt); refer back to Figure 11 and Figure 10 respectively. The parameters of the detection can be adjusted, but typically tilt is identified when the power variation is calculated to be 15 dB or more. The algorithm will also calculate a severity number between 0 and 100, with 0 being the least severe and 100 being the most severe. In this way, the severity can be broken down into yellow or red. An example configuration would be yellow for severity number between 0 and 80, and red severity for 80 to 100.

© 2020 SCTE•ISBE and NCTA. All rights reserved.

Adjacency – Identifies a group of channels with median amplitude values several dB higher than other channels in that part of the spectrum, likely caused by incorrect narrowcast injection levels; refer back to Figure 8. The algorithm calculates the median amplitude within the 6 MHz channel and triggers an impairment detection when the adjacent median amplitude differs (typically by 3 dB to 14 dB). An example severity range would be yellow ≤ 50 and red > 50.

Standing waves – Algorithm automation calculates changes in the median amplitude to determine when the signal includes amplitude ripple (standing waves); refer back to Figure 12. The algorithm can account for the natural tilt of the spectrum. Severity is calculated based on the difference between the min and max power level in the detected wave range. Example severity levels are yellow ≤ 7.5 dB and red > 7.5 dB.

Notch (suckout) – Algorithm detects when amplitude differences and high tilt are present in groups of channels; refer back to Figure 13 and Figure 14. Severity is based on the amplitude depth of the notch.

Rolloff – Can automatically detect non-flat loss of signal level at or near the upper end of the RF spectrum. The algorithm uses a rolling median and calculates severity by steepness of the roll-off amplitude over 4 dB.

Resonant peak – The algorithm detects areas of the spectrum where the amplitude maximum is higher than the average of the surrounding frequencies; refer back to Figures 16, 17, 18, and 19. Severity is determined by the difference between the maximum and the average amplitudes. Sample severity threshold is yellow at ≤ 7 dB and red > 7 dB.

9. Conclusion

Many DOCSIS 3.0 cable modems – and all DOCSIS 3.1 cable modems – support full band capture capability. FBC gives cable operators the equivalent of a spectrum analyzer in every home in which an FBC-capable modem has been installed. FBC spectral displays can show impairments such as ingress, frequency response problems, the presence of filters, incorrect narrowcast versus broadcast signal levels, and much more. Furthermore, those spectral displays are intuitive and easy to understand. A key benefit is that many problems can be identified remotely without the need to first roll a truck.

Some cable operators use FBC for plant maintenance and troubleshooting, and some operators and third-party vendors have incorporated FBC in their PNM tools. Yet many cable operators do not take advantage of FBC – technology that already exists in their networks – or are unaware of its capabilities.

The industry has been given a valuable and powerful tool for plant maintenance, and software exists to integrate FBC with operational practices. The opex is out there, waiting to be saved!

10. Abbreviations

4G	fourth generation [mobile telecommunications technology]
5G	fifth generation [mobile telecommunications technology]
ADC	analog-to-digital converter
AGC	automatic gain control
CCAP	converged cable access platform
CMTS	cable modem termination system
CPE	customer premises equipment
CSV	comma separated values

© 2020 SCTE•ISBE and NCTA. All rights reserved.

CW	continuous wave
dB	decibel
dBmV	decibel millivolt
DC	direct current
DFT	discrete Fourier transform
DOCSIS	Data-Over-Cable Service Interface Specifications
DSP	digital signal processing
FBC	full band capture
FFT	fast Fourier transform
FM	frequency modulation
HFC	hybrid fiber/coax
I	in-phase (real)
Hz	hertz
ISBE	International Society of Broadband Experts
kB	kilobyte
kHz	kilohertz
log	logarithm
LTE	long term evolution
MHz	megahertz
MIB	management information base
OFDM	orthogonal frequency division multiplexing
OSSI	operation(s) support system interface
PLC	1) physical layer link channel; 2) PHY link channel
PNM	proactive network maintenance
PSD	power spectral density
Q	quadrature (imaginary)
QAM	quadrature amplitude modulation
RBW	resolution bandwidth
RF	radio frequency
RxMER	receive modulation error ratio
SC-QAM	single carrier quadrature amplitude modulation
SCTE	Society of Cable Telecommunications Engineers
SNMP	Simple Network Management Protocol
TDR	time domain reflectometer
TFTP	Trivial File Transfer Protocol
TV	television
UHF	ultra high frequency

11. Bibliography & References

[Ref. 1]: Data-Over-Cable Service Interface Specifications DOCSIS 3.0 Operations Support System Interface Specification CM-SP-OSSIv3.0-I20-121113 (Cable Television Laboratories)

[Ref. 2]: Williams, Tom. “Correlating Return-Band Impulsive Noise Measurements from Houses with Sheath Current Induction Test Results,” 1999 NCTA Technical Papers

© 2020 SCTE•ISBE and NCTA. All rights reserved.

[Ref. 3]: Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Cable Modem Operations Support System Interface Specification CM-SP-CM-OSSIv3.1-I16-190917 (Cable Television Laboratories)

[Ref. 4]: DOCSIS® Best Practices and Guidelines PNM Best Practices: HFC Networks (DOCSIS 3.0) CM-GL-PNMP-V03-160725 (Cable Television Laboratories)

[Ref. 5]: Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Physical Layer Specification CM-SP-PHYv3.1-I17-190917 (Cable Television Laboratories)

[Ref. 6]: Data-Over-Cable Service Interface SpecificationsvDOCSIS® 3.1 CCAP™ Operations Support System Interface Specification CM-SP-CCAP-OSSIv3.1-I18-200610 (Cable Television Laboratories)

[Ref. 7]: Campos, Alberto; B. Currivan; C. Moore; T. Williams; "Upstream Cable Echoes Come In Two Flavors" *CED* magazine (on-line), February 2010. An enhanced version of the article was included in Appendix V of DOCSIS® Best Practices and Guidelines Proactive Network Maintenance Using Pre-equalization CM-GL-PNMP-V02-110623 (Cable Television Laboratories).

[Ref. 8]: PNM Best Practices Primer: HFC Networks (DOCSIS® 3.1) CM-GL-PNM-3.1-V01-200506 (Cable Television Laboratories)

© 2020 SCTE•ISBE and NCTA. All rights reserved.

12. Appendix

The following Python code is provided as a demonstration of how to retrieve and plot FBC data from a cable modem.

The script getFbcData.py should be called after a capture is initiated on a modem by setting the `docsIf3CmSpectrumAnalysisCtrlCmdEnable` object to true. The results are saved into the specified CSV file that can then be imported into a spreadsheet application such as Excel or be used by the showFbcData.py script.

12.1. File: getFbcData.py

Usage: getFbcData.py <SNMP community string> <cable modem IP address> <filename>

```
#!/usr/local/bin/python3
#
# THIS SOFTWARE IS PROVIDED BY THE AUTHORS AND CONTRIBUTORS "AS IS" AND
# ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED
# WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE
# DISCLAIMED. IN NO EVENT SHALL THE AUTHORS OR CONTRIBUTORS BE LIABLE FOR
# ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES
# (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES;
# LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND
# ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT
# (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS
# SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
#
# Collects docsIf3CmSpectrumAnalysisMeasAmplitudeData from cable modem and save to
# CSV file
#
# This script requires the following python3 packages have been installed
#   pysnmp
#
# Author: James Medlock, jmedlock@akleza.com
#

import sys, os, getopt
import plotly.express as px
from pysnmp.hlapi import *

# Define FBC SNMP OIDs used
docsIf3CmSpectrumAnalysisMeasAmplitudeData=".1.3.6.1.4.1.4491.2.1.20.1.35.1.2"

# Convert 2's complement 16 hex value to decimal
def twos(val):
  x = int(val, 16)
  if x > 32767:
    x = x - 65535
  return x

def main():
  ampdata = []
  for (errorIndication, errorStatus, errorIndex,
     varBinds) in bulkCmd(SnmpEngine(),
                CommunityData(str(sys.argv[1])),
                UdpTransportTarget((str(sys.argv[2]), 161)),
                ContextData(),
                0, 2,
                ObjectType(ObjectIdentity(docsIf3CmSpectrumAnalysisMeasAmplitudeData)),
                lexicographicMode=False):

    if errorIndication:
      print(errorIndication)
      break
    elif errorStatus:
      print('%s at %s' % (errorStatus.prettyPrint(),
                errorIndex and varBinds[int(errorIndex)-1][0] or '?'))
      break
    else:
      for varBind in varBinds:
```

© 2020 SCTE•ISBE and NCTA. All rights reserved.

```
        ampdata.append(varBind[1].prettyPrint()[2:])

  if len(ampdata) <= 1:
    print("No FBC data available")
    sys.exit()

  # Decode each AmplitudeData row and write frequency,amplitude values to output file
  with open(sys.argv[3], "w") as outF:
    for x in ampdata:
      centerfreq=int(x[0:8],16)
      freqspan=int(x[8:16],16)
      numbins=int(x[16:24],16)
      binspacing=int(x[24:32],16)
      resbw=int(x[32:40],16)

      startfreq = centerfreq - (numbins / 2 * binspacing)

      i = 0
      bin = 0
      while i < numbins*4:
        freq = startfreq + (bin * binspacing)
        j = 40 + i
        hexvalue = x[j:j+4]
        ampvalue = twos(hexvalue) / 100.0

        print(str(freq) + "," + str(ampvalue), file=outF)

        i += 4
        bin += 1

if __name__ == "__main__":
  if len(sys.argv) < 4:
    print("Usage: getFbcData.py <SNMP community string> <cable modem IP address> <filename>")
    sys.exit()

  main()

# End of file
```

12.2. File: showFbcData.py

Usage: showFbcData.py <filename>

```
#!/usr/local/bin/python3
#
# THIS SOFTWARE IS PROVIDED BY THE AUTHORS AND CONTRIBUTORS "AS IS" AND
# ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED
# WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE
# DISCLAIMED. IN NO EVENT SHALL THE AUTHORS OR CONTRIBUTORS BE LIABLE FOR
# ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES
# (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES;
# LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND
# ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT
# (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS
# SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
#
# Display FBC data stored in CSV file
#
# This script requires the following python3 packages have been installed
#   plotly
#   pandas
#
# Author: James Medlock, jmedlock@akleza.com
#
# Usage: showFbcData.py <filename>
#

import sys
import csv
import plotly.express as px

def main():
  xdata = []
```

© 2020 SCTE•ISBE and NCTA. All rights reserved.

```
  ydata = []
  with open(sys.argv[1]) as csvfile:
    csvData = csv.reader(csvfile, delimiter=',')
    for row in csvData:
      xdata.append(float(row[0]) / 1000000)
      ydata.append(float(row[1]))

  fig = px.line(x=xdata, y=ydata,
                labels={'x':'Frequency (MHz)', 'y':'Amplitude (dB)'},
                title='DOCSIS Cable Modem Full Band Capture')
  fig.update_layout({'plot_bgcolor': 'rgba(0, 0, 0, 0)', 'paper_bgcolor': 'rgba(0, 0, 0, 0)'},
            title={'x':0.5,'xanchor':'center'})
  fig.update_traces(hovertemplate='Frequency: <b>%{x:.2f} MHz</b><br>Amplitude: <b>%{y:.2f} dB</b>',
                    line_color='rgb(68,114,196)')
  fig.update_xaxes(showline=True, linewidth=2, linecolor='black', gridcolor='rgb(209,209,209)')
  fig.update_yaxes(showline=True, linewidth=2, linecolor='black', gridcolor='rgb(209,209,209)')
  fig.show()

if __name__ == "__main__":
  if len(sys.argv) < 2:
    print("Usage: showFbcData.py <filename>")
    sys.exit()

  main()

# End of file
```

© 2020 SCTE•ISBE and NCTA. All rights reserved.